GROWTH OF ICE ON LAKE MICHIGAN

John A. Heap
Vincent E. Noble

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FOREWARD

This research program was proposed to National Science Foundation and initiated by Dr. John A. Heap in January 1964. In August 1965, Dr. Heap accepted a position with the United Kingdom Government, and left the University of Michigan. He remained associated with the project in an advisory capacity, and direction of the program was assumed by Dr. Vincent E. Noble.

Heap was responsible for collection and evaluation of the ice-cover data, while Noble did an essentially correlative study of the relation of the thermal regime of the lake. It was therefore deemed appropriate that this final report appear in the form of two independent sections, the first section to be Heap's description of the ice cover, and the second Noble's description of the temperature structure of the lake.

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PART I

ICE COVER STUDIES, LAKE MICHIGAN

John A. Heap

INTRODUCTION

Compared with other seasonally ice bound waters of the world, peculiarly little is known about ice cover on the Great Lakes. Despite their importance as an economic artery in the heart of the continent (the tonnage shipped through the Great Lakes in an 8-month season surpasses that of most other shipping lanes of the world), the literature is restricted to lists of port openings on Lake Michigan (Conger 1908) and to the work of the Detroit office of the U. S. Weather Bureau in establishing a service to predict port openings at the beginning of the navigation season in all the lakes (Oak 1955, 1957; Oak and Meyers 1953; Thiele 1960).

In August 1962, the writer began work on a 6-months project sponsored by RAND Corporation to assemble, evaluate, and, if possible, map the ice distribution on Lakes Superior, Huron, and Michigan. The results showed that little useful purpose could be served by mapping the inadequate data available. A survey of the possible sources (U. S. Weather Bureau, U. S. Coast Guard, commercial shipping, car ferries, fishing tugs, civil airlines and the Canadian Department of Transport, Meteorological Branch) showed that the data were almost entirely restricted to the shore lines and, furthermore, to the latter part of the ice season, from February to April. Information on mid-lake conditions was almost non-existent apart from the Canadian data, which cover only the last six years and do not cover Lake Michigan. The results of this study are reported in greater detail in a report to RAND Corporation (Heap 1963a, b). Within the last two years, the U. S. Lake Survey has instituted a program for aerial reconnaissance of the ice cover on the Great Lakes. There is yet, however, only minimal coverage of Lake Michigan.

WINTER CHARACTERISTICS OF LAKE MICHIGAN

Lake Michigan covers almost four and a half degrees of latitude, so that the average January and February temperatures at Chicago, Ill., are 26.1 and

27.9F, respectively, while at Escanaba, Mich., the average temperature for these two months are 18.4 and 18.7F. As a result, in normal years more ice forms in the northern part of the lake than in the southern. The parts of the lake could be suitably divided by a line joining Sturgeon Bay Canal and Frankfort. The dominance of the north as an ice-forming region is magnified by the relatively shallow and landlocked waters of Green Bay and the area lying to the east of a line joining Sleeping Bear Point and Seul Choix Pointe. Fast ice tends to form in these areas. These locations are identified in Figure 1.

Around the remainder of the lake, characterized by straight, smooth coast lines, fast ice normally develops only in sheltered harbors and as a narrow fringe along the open coasts. This fast-ice fringe usually shows a succession of ridges parallel to the shore, for the genesis of which Zumberge and Wilson (1954) suggested an explanation.

In the mid-lake regions, out of sight of land, ice conditions remain a relatively unknown quantity. It is almost certain that more of the mid-lake region in the north is covered with ice than in the south, and it is also probable that there is more ice in the eastern half of the lake because of the predominance of stronger prevailing winds from the west (U. S. Weather Bureau 1958). If the eastward wind drift of ice across the lake is a significant factor in the average distribution, then the related Coriolis drift of the ice will tend to drive ice southward resulting in a more southerly ice limit on the eastern than the western side of the lake. Aerial reconnaissances of 10 and 23 March 1963 by the U. S. Lake Survey showed older, heavier and more concentrated pack on the eastern side of the lake with a generalized NW-SE ice edge across the lake. Knowledge of mid-lake concentrations of ice is so sparse that it is not very profitably to guess at the average proportion of the lake covered.

It is also difficult to give any general picture of the duration of ice coverage because the information previously available applies almost entirely to the annual date of opening of harbours. A harbour is closed when the last ship leaves in the early winter and is open when the first arrives in the spring--dates which are, at least in part, decided by factors other than ice coverage, such as the availability of marine insurance. A series of dates of complete freeze-up and break-up since 1900 are available for Menominee, Mich., (Fig. 2) which indicate that the average dates of freeze-up and break-up are

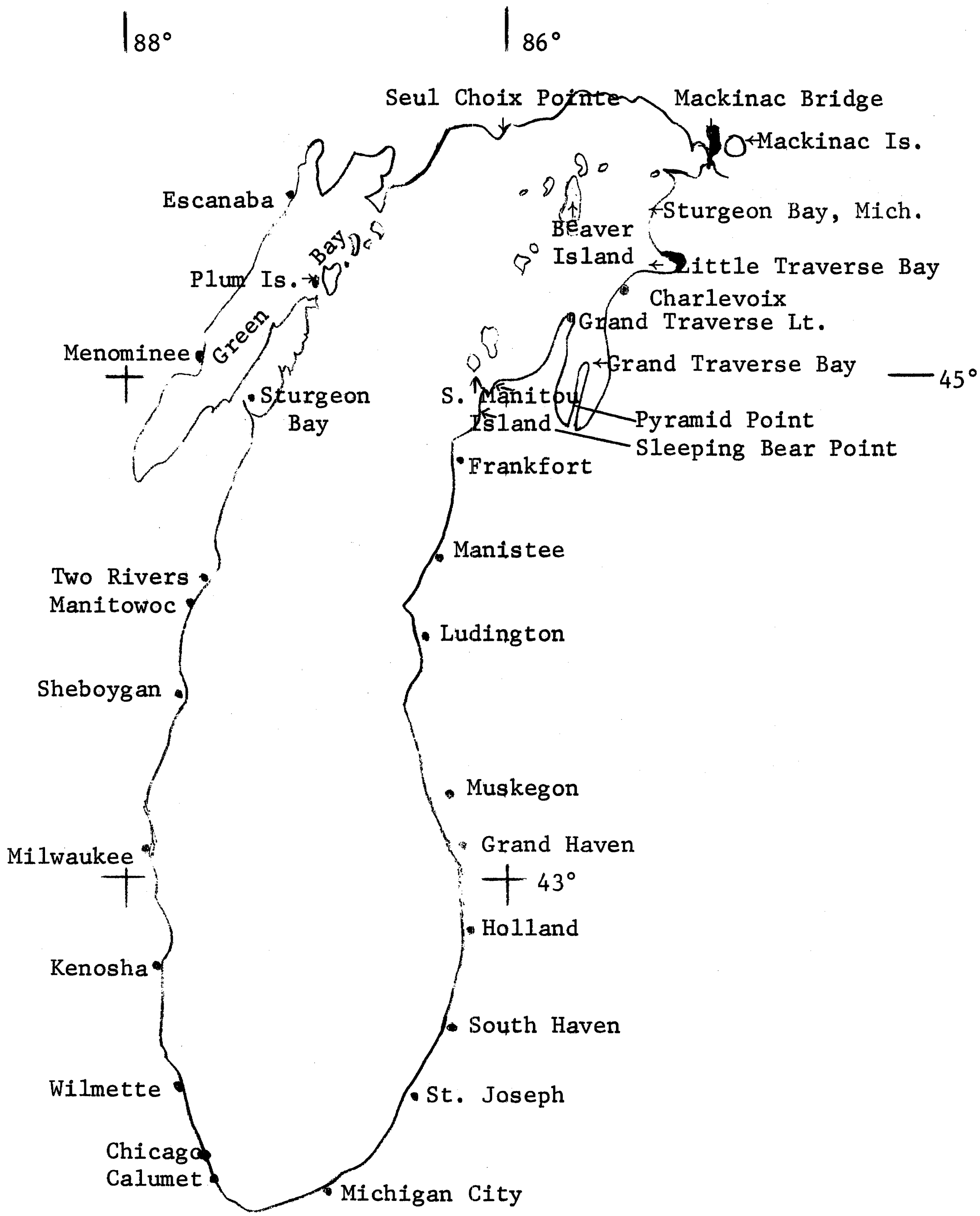


FIGURE 1. Lake Michigan.

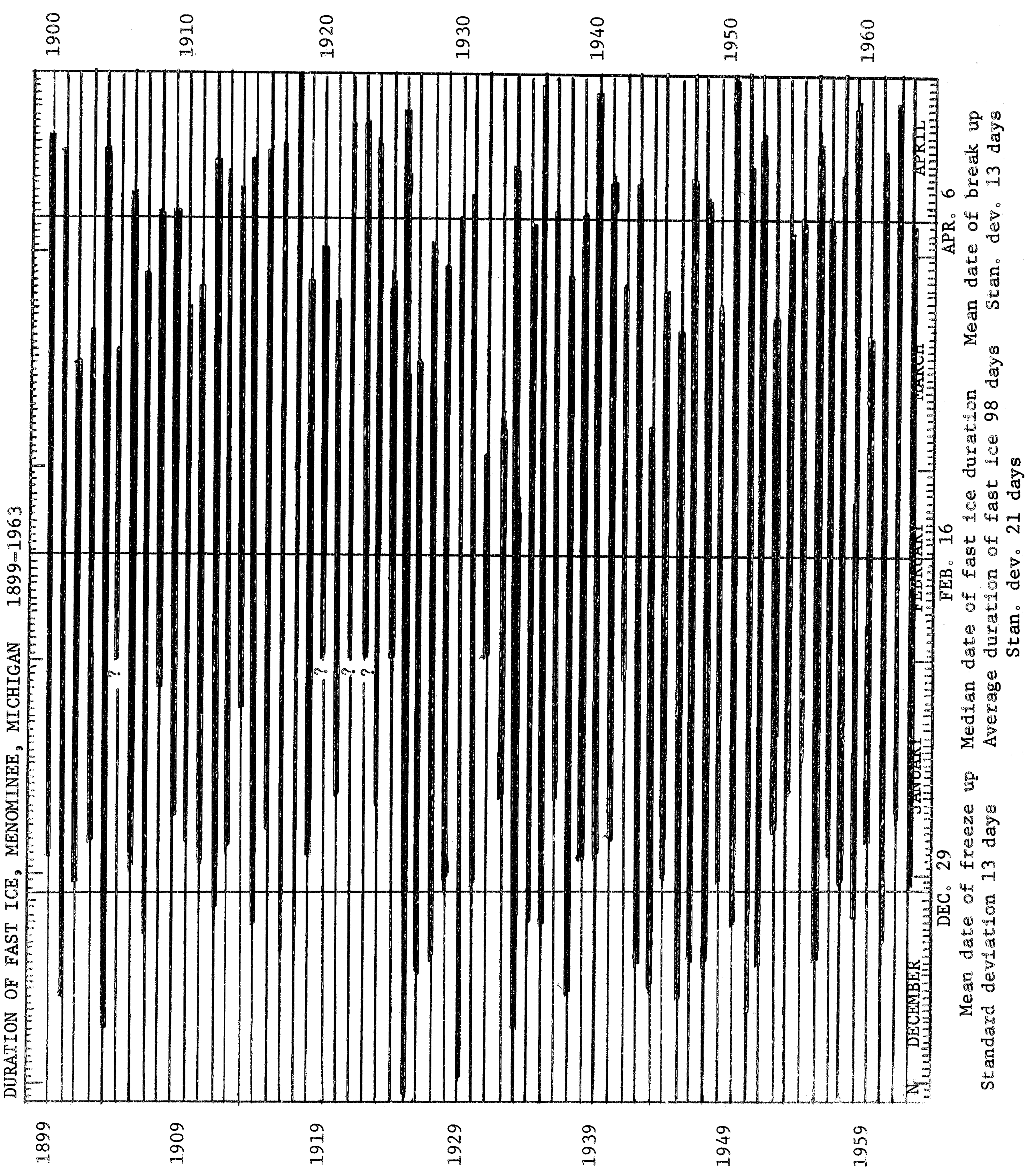

DURATION OF FAST ICE, MENOMINEE, MICHIGAN 1899-1963
1900
1910
1920
1930
1940
1950
1960
1899
1909
1919
1929
1939
1949
1959
N
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
DEC. 29
FEB. 16
APR. 6
Mean date of freeze up
Standard deviation 13 days
Median date of fast ice duration
Average duration of fast ice 98 days
Stan. dev. 21 days
Mean date of break up
Stan. dev. 13 days

FIGURE 2

29 December and 6 April respectively with standard deviations around their respective means of 13 days. The average duration of fast ice is 99 days with a standard deviation of 21 days. The maximum duration was 144 days in the 1925-26 season and the minimum was 31 days in the 1931-32 season. These figures suggest that wide variations are the rule in landlocked Green Bay, and there is no reason to think that the variation will be greater on the shores of the open lake. These deviations reflect the variations that are found in the weather over the lake. Mean monthly temperatures over the lake for December 1962 and January and February 1963, showed mean monthly anomalies for these months of -2.5, -10.0 and -7.5F respectively. Expressing these anomalies as percentages of the normal number of frost degree days ("freezing exposure") acting on the lake in each month, the three months experienced values of 132%, 206% and 205% respectively.

Various authorities on the economic viability of the Great Lakes region have suggested that an extension of the navigation season would greatly reduce the cost of shipping by using fewer ships for longer periods (Benford, Thornton and Williams 1962; Minnesota N.R.C. 1962; Thiele 1960). Since the hardest period for navigation is in the early phase of the break-up, the most likely extension would be into the growth period of the ice regime, about which least is known. Although there is an over-icing hazard at this time of year, it is believed to be amenable to forecasting techniques.

OBSERVATIONS, WINTER 1962-63

In October 1962, the writer asked a small group of volunteers at eight points around Lake Michigan to observe the ice from its first appearance to its final disappearance. Observation points were located at Mackinac Island, Mackinac Bridge, Seul Choix Pointe, Escanaba, Milwaukee, Chicago, and Ludington. Each observer was asked to complete a column of questions on a *pro forma* sheet (Fig. 3) by checking items appropriate to the day's observation. The form was designed to incorporate one or two internal checks on the observers' answers. The program was entirely satisfactory within its primary limitation of being unable to indicate position accurately. To overcome this limitation, mapped observations were used during the following season.

In March 1963, an aerial reconnaissance program of the ice on Lake Michigan was initiated by the U. S. Lake Survey. Three flights were made on March 10, 23, and April 6. In early March 1963, a car journey around the lake was

UNIVERSITY OF MICHIGAN ICE OBSERVING
PROGRAM, 1962-63, LAKE MICHIGAN

WEEK ______________________________ to ______________________________
Month Day Month Day
STATION ______________________________ OBSERVER ______________________________

HEIGHT OF OBSERVATION POINT ______________________________

		SAT	SUN	MON	TUE	WED	THU	FRI
	DURING PREVIOUS 24 HOURS							
1.	Ice is or has been present							
2.	There has been no ice							
	DURING PREVIOUS 24 HOURS THE ICE SITUATION HAS:							
3.	Changed							
4.	Not changed							
	DURING PREVIOUS 24 HOURS ICE HAS:							
5.	Formed by freezing							
6.	Consolidated							
7.	Drifted in							
8.	Melted							
9.	Broken up							
10.	Drifted out							
11.	Windrowed							
	FAST ICE IS:							
12.	Absent							
13.	Present							
14.	Width*	y	y	y	y	y	y	y
		m	m	m	m	m	m	m
15.	To horizon							
	Thickness	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx
16.	Measured — Inches {							
17.	Estimated							
	DRIFT ICE IS:							
18.	Absent							
19.	Present							
20.	Width*	y	y	y	y	y	y	y
		m	m	m	m	m	m	m
21.	To horizon							
	Thickness	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx
22.	Measured — Inches {							
23.	Estimated							
	Concentration	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx
24.	less than 1/10th							
25.	1/10-4/10ths							
26.	5/10ths-7/10ths							
27.	8/10ths-9/10ths							
28.	10/10ths							
29.	Not estimated							

*y = yards; m = miles
Strike out which does not apply.

FIGURE 3

made to visit the ice observers and to see whatever could be seen of the ice. In early April a cruise was made on the U. S. Coast Guard icebreaker MACKINAW from Cheboygan, Mich., through the Straits of Mackinac to Green Bay. This was in a state of decay which showed up its internal structure to advantage. These two journeys and the results of the flight observations emphasized the need for study of ice as a mobile three-dimensional distribution. For this reason, the 1963-64 research program was aimed observing the distribution of ice, its growth and decay, and the way pack ice moves in the lake.

The 1962-63 winter set new low temperature records at many places around the lake. Ice first appeared all around the lake on 11 or 12 December after a cold snap when the temperature had dropped to a mean of 16F for two days. Green Bay was seen to freeze solid at Escanaba and Menominee in the next cold period around 29 and 30 December. By the end of the year, the fast ice fringe around the lake was reasonably complete; there was also some drift ice but the amount is not known. From 10 January to about 3 February the temperatures were abnormally low, and it is believed that this period saw the greatest formation of ice. Grand Traverse Bay became completely fast, and there was fast ice east of a line connecting Pyramid Point and Seul Choix Pointe. By the end of January, consolidated pack stretched to the horizon (about 10 miles) at Ludington, pack of 5/10 to 7/10 coverage lay to the horizon off Milwaukee, and a thin skin of fast ice reached 5 miles off Chicago. On 30 January the Ludington-to-Milwaukee Ferry reported a 10/10 coverage of thin ice all across the lake. Apart from these observations, mid-lake conditions are unknown.

In February, conditions remained stable with a probable increase in the extent of ice cover until about 20 February when gale-force westerly winds for two days produced heavy windrowed ice up to 7 miles off shore at Ludington. Rafting and hummocking resulting from this storm probably caused a diminution of the areal extent of ice without decreasing the volume of ice present.

On 10 March the first ice reconnaissance flight over Lake Michigan was made by the U. S. Lake Survey. Fast ice covered Green Bay and east of the line taken up in January from Pyramid Point to Seul Choix Pointe. Winter ice of 7/10 to 9/10 concentration lay in the eastern half of the lake, while more young ice lay in the western half. The southwestern part of the lake was largely open water. By the second reconnaissance on 23 March, the areas of fast ice were the same but the lake was mostly open south of a line joining Manitowoc and Muskegon, and a large area of open water had opened up in the

central part of the lake north of Frankfort. As on 10 March, the ice in the eastern half of the lake was older, heavier, and more concentrated than in the western half. The last flight on 6 April showed no ice in the lake apart from 8/10 to 9/10 pack in the area previously fast. Only small areas of fast ice remained in Green Bay, Grand Traverse Bay, Little Traverse Bay, and Sturgeon Bay, Michigan.

The shore observations during March and April show that fast ice began to rot noticeably in the Straits of Mackinac and in Grand Traverse Bay on 23 March and that the ice began to break up in these areas, and in Green Bay between 3 and 7 April. The last ice was seen in Grand Traverse Bay on 18 April and in the Straits of Mackinac on 23 April.

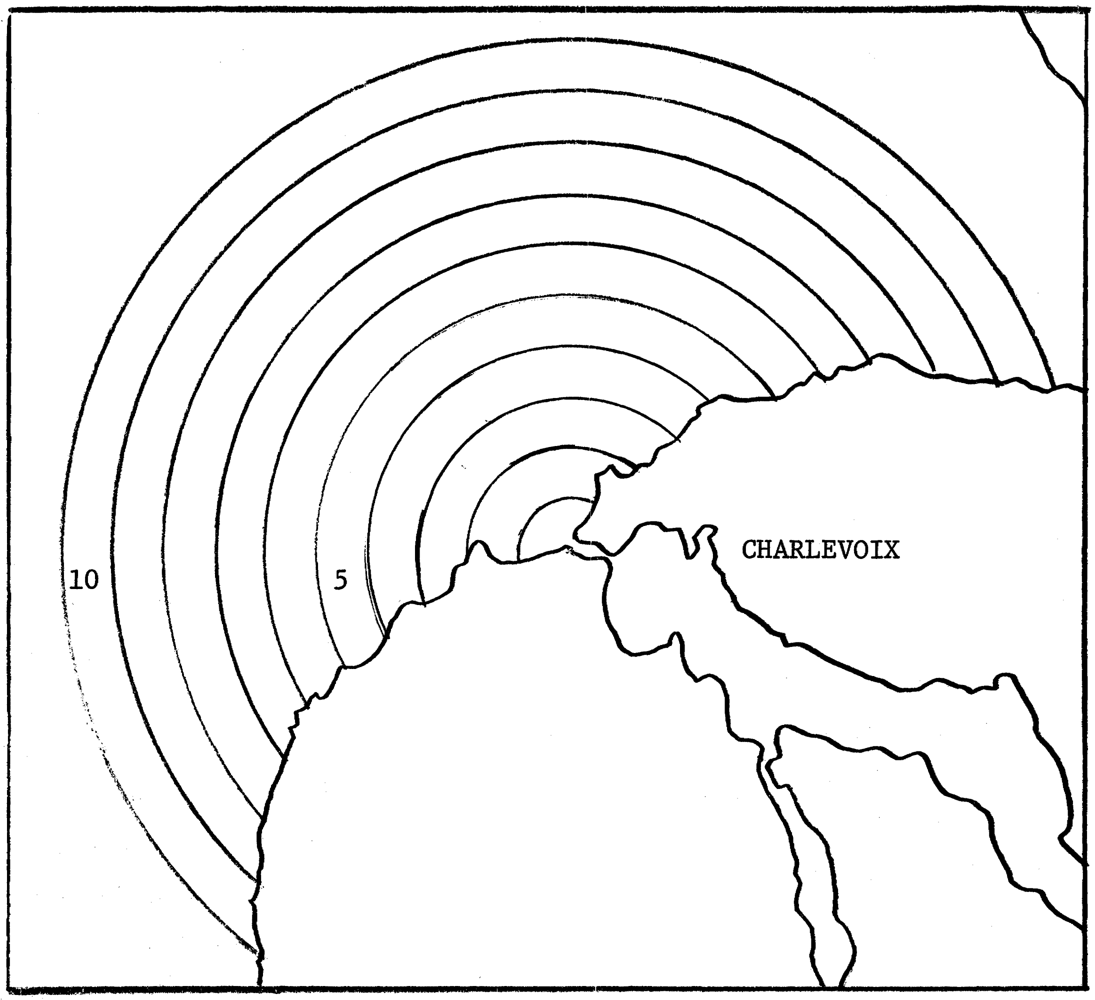
Analysis of the area of the lake covered with ice on the days of aerial reconnaissance shows that on 10 March, 62% of the lake was ice covered. By 23 March the proportion has dropped to 40%, and by 6 April to 14%.

OBSERVATIONS, WINTER 1963-64

The program for shore-based ice observations during the 1963-64 winter season was carried out with the full support and cooperation of the U. S. Coast Guard. Observations were taken at 26 shore stations and from the commercial Beaver Island-Charlevoix flight. The shore stations used in the reporting net are: Grand Traverse Bay, Beaver Island, S. Manitou Is., Plum Is., Charlevoix, Grand Traverse Light, Manistee, Frankfort, Ludington, Muskegon, Grand Haven, Holland, South Haven, St. Joseph, Michigan City, Calumet, Wilmette, Kenosha, Milwaukee, Two Rivers, Sheboygan, Sturgeon Bay Canal, Menominee, Escanaba, and Seul Choix Pointe.

To obtain better geographic information about the distribution of local ice, the 1962-63 station reporting form was replaced with local maps prepared for each station. A typical reporting map prepared for the 1963-64 season is shown in Figure 4. Instructions provided to the shore station observers are presented in Appendix A.

The winter of 1963-64 was very mild, with an excpetionally light development of ice on Lake Michigan. As of 20 December 1963, in the open lake south of Sturgeon Bay-Frankfort, ice was restricted to fringes of fast ice rarely more than 200-300 yards wide. Many stations reported small amounts of brash off shore, but that was probably only of local significance. Otherwise the lake was estimated to be clear. In the shallow water of Green Bay, ice was



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LAKE MICHIGAN ICE PROJECT, 1963-64

Date .... 196 . Time of observation local .... hrs.

Observation point .... Height of ob. point .... ft.a.l.w.d.

Visibility .... miles. Temperature at time of observation .... °F

Wind direction .... °. Wind speed, Beaufort scale ....

Observer .... or knots ....kts.

Distance of horizon from given heights above lake:

8 ft ... 3 miles	32 ft ... 6 miles	72 ft ... 9 miles
14 ft ... 4 miles	43 ft ... 7 miles	88 ft ... 10 miles
22 ft ... 5 miles	57 ft ... 8 miles	

FIGURE 4. Typical 1963-64 map.

increasing, but generally, the ice situation appeared to show the effects of the persistently warm fall of 1963.

On 24 January the summary of the ice situation was reported as: "This has been a bad week for the Lake Michigan Ice Project! There has been a general decrease in the amount of ice in the lake as a result of persistently above freezing temperatures. The aerial survey made by the U. S. Lake Survey (64-M-2) showed that ice was restricted to Green Bay, with small areas of pack ice blocking the Straits of Mackinac and at the southern end of the lake, leaving the remainder of the lake open."

There was a slight increase in the amount of ice due to colder temperatures around 10 February, but a warming trend which occurred a week later again reduced the ice cover. On 6 March the summary read: "Conditions appear to be much the same as last week. There is still some ice concentratee in the southeastern corner of the lake, but it appears to have decreased considerably since last week. Apart from fast ice in parts of Green Bay and very close pack ice west of the Straits of Mackinac, the remainder of the lake is open."

On 10 April the Lake Survey aerial reconnaissance (64-M-3) showed some ice against the western shore of the Door Peninsula, some in Big Bay de Noc, and some around the Straits of Mackinac. On 15 April the Beaver Island flight from Charlevoix reported open water in all directions. This appeared to mark the final phase of the 1963-64 ice season in Lake Michigan.

Detailed weekly abstracts from the daily ice reporting maps are presented in Appendix B.

The lack of ice during the 1963-64 winter made it impossible to traverse the ice field for thickness measurements or to plant markers for ice drift studies.

OBSERVATIONS, WINTER 1964-65

The winter season 1964-65 extended beyond the active ice-study period undertaken within the framework of this program. However, in the interest of maintaining a continuity of basic ice data, arrangements were made for this project to prepare ice-observation maps for distribution to the observing shore stations by the U. S. Weather Bureau. The instructions to the observers were modified slightly for this second season of reporting, and the revised instructions are presented in Appendix C. Data contained in the 64-65 station maps are currently being abstracted by the writer and will be made available

upon completion.

Termination of the present program has coincided with an increased output from the ice study program conducted by the U. S. Lake Survey. The documentation of Lake Michigan ice from aerial reconnaissance reported by Wilshaw and Rondy (1965) still has its primary emphasis on the upper portion of Lake Michigan, but does contain much valuable information. It is anticipated that subsequent years of implementation of the sophisticated reconnaissance program by the U. S. Lake Survey will begin to produce the necessary detailed data in the space- and time-scales necessary for a study of the growth, movement, and decay of ice on Lake Michigan.

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APPENDIX A

GREAT LAKES RESEARCH DIVISION

INSTITUTE OF SCIENCE AND TECHNOLOGY

UNIVERSITY OF MICHIGAN

Lake Michigan Ice Project, 1963-64

INSTRUCTIONS FOR COMPLETION OF
SHORE-BASED ICE OBSERVATION DATA SHEETS

John A. Heap
Great Lakes Research Division
1077 N. University Building
University of Michigan
Ann Arbor, Michigan

November 1963

INSTRUCTIONS FOR COMPLETION OF
SHORE-BASED ICE OBSERVATION DATA SHEETS

1. INTRODUCTION

The United States Coast Guard, 9th District, cooperating with the University of Michigan's ice project on Lake Michigan, is supporting the shore-based ice observation program at 22 Coast Guard stations around the lake. The object of the program is to obtain a daily record of the ice conditions within view of each station throughout the ice season. In particular, information is required on the formation, extent of fast ice, concentration of pack ice (drift ice), and the melting, break-up and final dispersal of the ice in the spring. Maps are provided for recording observations because it is easier to complete a map than attempt to describe a complex pattern of ice distribution.

The shore-based observation program is an essential part of a study of the formation, growth, movement and decay of ice on Lake Michigan, which also includes aerial observations and measurements of ice thickness and ice drift. The long-term purpose of the study is to acheive methods of forecasting the formation, growth and decay of ice.

A list of useful terms and their definitions is appended.

2. METHODS OF OBSERVING

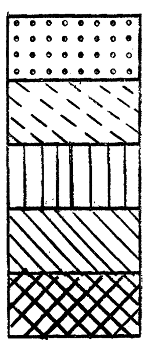
1. Observations should be started on the day that the first ice is seen and should continue until the last ice is seen.
2. Observations should be made from the highest convenient point above the lake surface so that the maximum field of view is obtained.
3. Observations should be made daily from the same point and at the same time. If the weather does not permit an observation at the usual hour, it is better to make one at some other time rather than miss that day altogether.
4. When at the observation point it will be found most convenient to observe in the following order:
   - A) Note range of visibility.
   - B) If there is any fast ice present, plot its outer edge.
   - C) If there is pack ice present, plot areas of approximately equal concentration and mark the number of tenths concentration in each area.
   - D) Mark on each area of similar concentration the average size of the constituent ice floes.
   - E) Note signs of pressure or decay.
   - F) If possible, estimate the thickness of the pack ice.
   - G) On returning to the station, note the temperature, wind direction and speed, and, if possible, the maximum and minimum temperatures during the previous 24 hours.

The following are notes in expansion of items A through G:

A) Visibility: Visibility is primarily limited by the height of the observer above the lake surface and may be further limited by weather conditions. At the foot of each observation map will be found a list of the distances to the horizon from various heights above the water level. Having ascertained the height of your normal observation point above the lake, make a mental note of how far you can see over the lake. (Note that each map is marked with concentric rings one mile apart.) Only abnormal refraction conditions will alter the range of visibility by producing mirages of conditions beyond the horizon. In the place reserved for entering visibility conditions it is only intended that a note should be made if the normal visibility to the horizon is restricted by weather conditions such as fog, frost smoke, falling or driven snow. In such cases note the range of limited visibility.

B) Fast ice: Frequently the fast ice will be a mere strip, a few yards wide, along the shore. In this case draw a solid pencil line along the shore line and label it 'Fast ice fringe.' If it is more than about 200 yards wide, it should be possible to indicate its extent on the map.

C) Ice concentration: Since it is not possible to plot each individual ice floe, it is normal practice in ice reconnaissance to show areas in which the concentration of ice is approximately the same. (See example map.) The categories of ice concentration as used by the U. S. Hydrographic Office are as follows:



less than 1/10 coverage - open water

1/10 to 5/10 coverage - open pack ice

5/10 to 8/10 coverage - close pack ice

8/10 to 10/10 coverage - very close pack ice

10/10 coverage (no water) - consolidated pack ice or fast ice

D) Size of ice floes: The size of constituent ice floes in pack ice bears an important relationship to the potential vanigability of the ice. Therefore, it is necessary to know the approximate average size of the floes. The following are the most widely used categories of size:

Brash ice	less than 2 yards across
Ice cake	2-10 yards across
Small floes	10-200 yards across
Medium floes	200-1000 yards across

Big floes 1000 yards-6 miles across
Vast floes more than 6 miles across

E) Pressure: The two most obvious results of pressure in ice are rafting and hummocking. Both are the result of ice, driven by the wind, meeting the coastline or another ice sheet. Rafting, a process similar to pushing together a deck of splayed out playing cards, results in a rapid increase in ice thickness. It is more usually observed in thin ice less than about 6 inches thick, but is occasionally found in much thicker ice. Sufficiently severe pressure to produce windrows (pressure ridges) is most frequently exerted against the shoreline of the lake. On a scale of the maps provided, the exact location of a windrow etc. cannot be marked, but the following symbols can be used to indicate that pressure phenomena are present:

 Rafting

 Windrows

I would, however, be grateful for any notes you can write about the way, and under what conditions, rafting and hummocking occur.

Decay: The first signs of the spring decay of ice will be an increasing greyness of the hitherto white snow surface. As the snow on top of the ice melts, the slight irregularities in the ice surface will concentrate the slushy melt water giving a mottled appearance to the ice. After heavy rain, or an unseasonably hot day, the darker areas may turn into puddles. Once the ice is well rotted the wave action and increased water turbulence in a storm can dissipate and melt the ice very quickly. Symbols are:

Rotting Ice . . Rn
Puddles . . . . Pd

(Note that a grey tone can also be given to the ice by waves breaking over the edge of the ice and flooding the surface at any time during the ice season.)

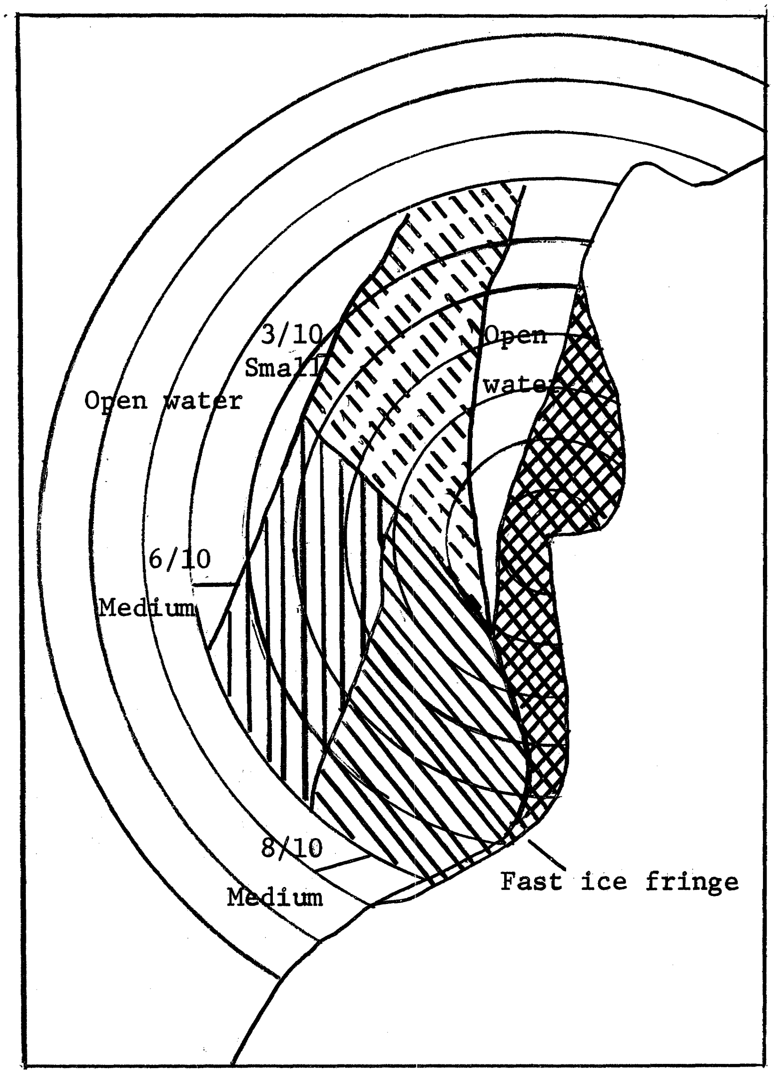
F) Ice thickness: An estimate of the thickness of pack ice in the lake should be given. It is difficult to make this estimate accurately and the only guide that can be given is that between 1/10 and 2/10 of the total thickness shows above the water level, i.e. if one inch shows above the surface, the total thickness will be between 5 and 10 inches. The normal density of lake ice is about 0.9 implying that only 1/10 will show above the surface with 9/10 below; however a snow cover can increase the apparent thickness above the surface without increasing the total thickness by the proportion of 1 to 9.

G) Meteorological data: Temperatures should be given in degrees Fahrenheit, wind direction in degrees of a circle or points of the compass, and wind speed in knots or according to the Beaufort scale. If it is not possible to give the absolute maximum and minimum air temperatures during the past 24 hours, then write on the back of the chart all the temperatures recorded, at the change of the watch or at synoptic hours, since the previous observation.

Short cuts: If there is no change in the distribution of water and/or ice since the previous observation, write 'NO CHANGE' across the face of the map. If there is open water or fast ice to the horizon write 'OPEN WATER' or 'FAST ICE TO THE HORIZON.'

3. RETURNING COMPLETED DATA SHEETS

In order to keep track of the ice situation, and so that data can be abstracted for use by the U. S. Coast Guard, Lake Survey and Weather Bureau, it is requested that the completed maps of Saturday through Friday be mailed on Friday evening each week. Stamped and addressed envelopes are provided for this purpose. The envelopes should not be sealed as they will be third class material.



Scale 1:240,000

LAKE MICHIGAN ICE PROJECT, 1963-64

Date January 24, 1964 Time of observation (local) 1200 hrs.

Observation Point Light house Height of ob. point 47 ft. a.l.w.d.

Visibility unlimited miles Temperature at time of ob. 26 °F

Temperature maximum 29 °F Minimum 16 °F in past 24 hours

Wind direction 045° Wind speed, Beaufort scale 4

or knots 13 kts.

(Note that distance of horizon from 47 ft. above lake surface is 7 miles.)

APPENDIX: <u>A list of useful terms in describing ice and ice distribution</u>

BRASH ICE	Accumulation of small fragments not more than 2 yards across, the wreckage of other forms of ice.
CLOSE PACK ICE	Composed of floes mostly in contact. Ice cover 5/10 to 8/10.
CONSOLIDATED PACK ICE	Pack ice composed of floes that are frozen together. Ice cover 10/10.
FAST ICE	Ice which remains fast, generally in the position where originally formed, and which may attain considerable thickness. It is found along coasts, where it is attached to the shore, or over shoals.
FRAZIL CRYSTALS	Fine spicules or plates of ice, suspended in water. Usually the first sign of ice.
FROST SMOKE	Fog-like clouds, due to the contact of cold air with relatively warm water, which appear over newly-formed leads and pools or leeward of the ice edge, and which may persist while young ice is forming. (Also known as sea smoke, lake steam.)
ICE BLINK	A typical whitish glare on low clouds above an accumulation of distant ice. It is especially glowing when observed on the horizon. q.v. Water Sky.
ICE COVER	The amount of ice encountered; measured in tenths of the visible water surface covered with ice.
ICE EDGE	The boundary at any given time between open water and floating ice of any kind, whether pack ice or fast ice.
ICE FLOE	A single piece of floating ice, other than fast ice, of any size larger than 10 yards across.
ICE RIND	A thin, elastic, shining crust of ice, after formation on quiet water. Thickness less than 2 inches. It is easily broken by wind or swell, and makes a tinkling noise when passed through by a ship.
OPEN PACK ICE	Floes seldom in contact with many leads and pools. Ice cover 1/10 to 5/10.
PACK ICE	Term used in a wide sense to include any area of floating ice, other than fast ice, no matter what form it takes or how it is disposed. (Also known as drift ice.)
PANCAKE ICE	Pieces of newly-formed ice, usually approximately circular, about 1 foot to 3 yards across, and with raised rims, due to the pieces striking against each other, as the result of wind and swell.

VERY CLOSE PACK ICE	Almost all floes in contact with each other with little water showing. Ice cover 8/10 to 10/10.
WATER SKY	Typical dark patches and strips on low clouds over a water area enclosed in ice or beyond its edge. It is due sometimes to an open water area beyond the horizon. (q.v. Ice Blink.)
WINTER ICE	More or less unbroken level ice, originating from young ice, and more than 6 inches thick.
YOUNG ICE	Newly-formed level ice generally in the transition stage of development from ice rind, or pancake ice to winter ice; thickness from 2 to 6 inches.

APPENDIX B

WEEKLY SUMMARY AND ABSTRACTS, ICE SITUATION 1963-64

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UNIVERSITY OF MICHIGAN - GREAT LAKES RESEARCH DIVISION
Lake Michigan Ice Project, 1963-64

Station	Ice Situation	Temp. °F
	ABSTRACT NO. 1, 1963	(1.= Mean Max. 2.= Mean Min. 3.= Mean)
	Summary: In the open lake, south of Sturgeon Bay-Frankfort, ice is restricted to fringes of fast ice rarely more than 200-300 yards wide. Many stations report small amounts of brash off shore, but this is probably only of local significance. Otherwise lake is estimated to be clear. In the shallow water of Green Bay, ice is increasing and may consolidate after a further cold spell. Generally, the ice situation appears to show the effects of the persistently warm fall of 1963. General winds were westerly.	
MANISTEE 20 Dec.	Fast ice fringe 200 yards wide.	3. 15
SOUTH HAVEN 20 Dec.	Fast ice fringe 200 yards wide with narrow fringe of brash beyond.	3. 15
ST. JOSEPH 15-20 Dec.	Fast ice fringe growing from 3 yards wide to 65 yards wide by the end of the week. Small amounts of brash intermittently present beyond fast ice. Otherwise lake is open.	1. 22.5 2. 13.3 3. 17.7
MICHIGAN CITY 20 Dec.	Fast ice fringe up to 600 yards wide with open water beyond.	3. 14
WILMETTE 14-20 Dec.	Observations throughout week obscured by lake steam, visibility varying from 300 ft to 1-1/2 miles. Harbor completely frozen over. Fringe of fast ice present throughout week growing from under 3 yards to more than 25 yards wide. Brash ice lying beyond fast ice, about 1/10 ice cover.	1. 12.7 2. 1.9 3. 7.3
MILWAUKEE 10-20 Dec.	Ice rind first seen in harbor 10 Dec., since when varying amounts of ice in the harbor, up to 5" thick, with open water beyond breakwater.	1. 11.7 2. -5.4 3. 3.2
SHEBOYGAN 10-20 Dec.	Pancake ice from river first seen in harbor, 10 Dec. 19-20 Dec. observations show fast ice fringe with brash to edge of limited visibility (2-1/2 miles).	
TWO RIVERS 12-20 Dec.	Fast ice fringe and ice rind in harbor first seen 12 Dec. By week's end fast ice fringe varying from 5-50 ft wide and 1-6 ft thick due to mechanical build-up by wind and waves. Small amounts of broken up ice rind and brash intermittently present beyond the fast ice.	1. 16.3 2. 5.4 3. 10.9

Station	Ice Situation	Temp. °F
STURGEON BAY CANAL 16-20 Dec.	16-20 Dec., fringe of fast ice up to 200 yards wide. 20 Dec., pack ice from 5/10 to 8/10 cover, present to limit of visibility (4 miles).	1. 15.0 2. 0.7 3. 7.8
MENOMINEE-MARINETTE 15-20 Dec.	Pancake ice first seen to north of lighthouse, 15 Dec. 17 Dec. 10/10 coverage of vast floes of thin ice to limit of visibility (7 miles) entirely dissipated by 18 Dec. By weeks end fast ice increasing rapidly. About 3/10 coverage of brash and cakes to 5 miles out with open water beyond.	1. 17.7 2. 4.2 3. 10.9
SEUL CHOIX POINTE 12-20 Dec.	Fast ice fringe to east of Pointe on 12 Dec., grew to 600 yards wide by weeks end with varying amounts of ice rind and brash in the bay between the Pointe and Port Island. Fast ice fringe started to form to west of Pointe on 18 Dec. and now growing slowly.	1. 19.8 2. 8.8 3. 14.3

ABSTRACT NO. 2, 1963

<u>Summary</u>: The cold temperatures of last week held until 22/23 Dec. followed by warmer temperatures for the remainder of the week. Winds were generally westerly with stronger winds in the southern part of the lake. More drift ice is apparent in the southern end of the lake from Wilmette to St. Joseph, otherwise the main body of the lake is ice free.

MANISTEE 21-27 Dec.	Fast ice fringe reduced from 300 yards wide at beginning of week to 150 yards wide at week's end. Otherwise open water to horizon apart from narrow strip of 1/10 small floes on 23 December.	
GRAND HAVEN 21-27 Dec. (incomplete)	Fast ice fringe to north and south of harbor increased during week. Open water in lake apart from small patches of pancake ice and brash.	
HOLLAND 22-28 Dec. (incomplete)	Fast ice fringe present in all observations. Open brash and ice cakes present at beginning of week to limit of visibility (6 miles). 25-28 Dec. ice restricted to local patch of cakes around harbor mouth.	
ST. JOSEPH 21-27 Dec.	Fast ice 600 yards wide increasing to about 1000 yards by week's end. Narrow fringe of 9/10 pack beyond fast ice on 21-22 Dec. 23-27 Dec. pack ice up to 5 miles off shore, varying between 6/10 and 9/10 coverage. About 10" thick at week's end.	1. 33.0 2. 22.7 3. 27.8
MICHIGAN CITY 21-27 Dec.	Fast ice fringe up to half a mile wide all week. 23-25 Dec. varying amounts of pack ice and open water, usually arranged in strips parallel to the shore line. 26-27 Dec. open water to horizon.	1. 27.4 2. 17.3 3. 22.3
WILMETTE 21-27 Dec.	Fast ice fringe 100-150 yards wide. 21-23 Dec. close pack to horizon (4 miles). 24 Dec. 2 miles wide shore lead with close pack beyond, 25 Dec. open pack to horizon followed by open water to week's end.	

Station	Ice Situation	Temp. °F
MILWAUKEE 21-27 Dec.	At beginning of week fast ice in northern end of harbor with pack ice in southern. Only small amount of fast ice left by week's end. Open water beyond breakwaters apart from small area of close pack on 23 Dec.	1. 27.4 2. 13.1 3. 20.2
TWO RIVERS 21-27 Dec.	Fast ice fringe a few feet wide with a narrow fringe of open brash lying beyond the fast ice until 24 Dec. 25-27 Dec. open water to horizon.	1. 25.3 2. 15.3 3. 20.3
SHEBOYGAN 21-27 Dec.	Fast ice fringe all week about 200+ yards wide. 1/10-3/10 coverage of brash and cakes up to 5 miles out at the beginning of the week with open water beyond. No drift ice on 25 and 26 Dec. By week's end small area of 3/10 small floes 2 miles off shore.	
STURGEON BAY CANAL 21-27 Dec.	Narrow fast ice fringe along coastline 100+ yards wide. Small amount of open pack in lake on 21 Dec., thereafter open water to end of the week.	1. 27.3 2. 15.0 3. 21.1
MENOMINEE-MARINETTE 21-27 Dec.	Fast ice fringe along shoreline, otherwise ice restricted to open brash and small floes within 5 miles of shore with open water beyond.	1. 26.8 2. 12.9 3. 18.8
ESCANABA 20-27 Dec.	(First shore ice seen on 11 Dec.) At beginning of week fast ice fringe on east shore of Little Bay de Noc 3-15 yards wide, otherwise open. 22-23 Dec. calm and low night temperatures produced young ice over Bay. 25 Dec. young ice blown out, leaving fast ice fringe and fast ice north of Gladstone. No change to week's end.	
SEUL CHOIX POINTE 21-27 Dec.	Fast ice fringe reduced during week to about 600 yards wide in the bay to east of Pointe. Narrow fringe of fast ice present to west of Pointe otherwise open water to horizon all week.	

ABSTRACT NO. 3, 1963-64

Summary: There has been little apparent increase in the amount of ice in the lake during this week. Low temperatures until the end of the year produced young ice at some stations on the western shore which had disappeared by 2 Jan. Southwest winds on 31 Dec. brought high concentrations of light pack to stations on the central eastern shoreline which diminished considerably under the influence of unseasonably warm weather during the rest of the week.

MANISTEE 28 Dec.- 3 Jan.	Fast ice fringe extending 100 yards from shore at beginning of week but by week's end it had diminished to 25 yards wide extending only about a mile north and south of the harbor breakwaters. Open water to horizon all week.	1. 24.3 2. 16.3 3. 20.3

Station	Ice Situation	Temp. °F
MUSKEGON 1-3 Jan.	Fast ice fringe which has been forming since 14 Dec. is now about 200-300 yards wide. Apart from a narrow strip of close pack lying against the fast ice to the south there has been open water to the horizon (7 miles) between 1 and 3 Jan.	
GRAND HAVEN 28 Dec.- 3 Jan.	Narrow, rafted and windrowed fast ice fringe present all week with areas of 1/10 coverage pack lying beyond until 31 Dec. when the ice within 4 miles of the shore concentrated to 5/10. By 1 Jan. this ice had concentrated to 8/10 with ice rind lying up to 4 miles from shore. At week's end there was open water to the horizon (7 miles) with close pack ice lying up to 1/2 mile from shore.	
HOLLAND 28 Dec.- 3 Jan.	Narrow fast ice fringe present all week with open water beyond through 30 Dec. On 31 Dec. close pack ice visible to horizon (5 miles) which consolidated against the shore producing a 1/2 to 3/4 mile wide fast ice fringe. By week's end fast ice broke back almost to the shore leaving only a mile wide fringe of close pack ice with open water beyond.	
SOUTH HAVEN 28 Dec.- 3 Jan.	Fast ice fringe almost half a mile wide with open water beyond through 30 Dec. On 31 Dec., very close pack ice visible to horizon (5 miles) which moved slowly off shore during 1 Jan. leaving open water to horizon on 2 Jan. and a slightly wider fast ice fringe. By week's end fast ice fringe almost 3/4 mile wide with a mile wide strip of very close pack ice beyond. Open water from about 1-1/2 miles out to horizon.	1. 23.7 2. 14.6 3. 19.1
BENTON HARBOR-ST. JOSEPH 28 Dec.- 3 Jan.	Fast ice fringe about half mile wide all week. All week there was a 2-3 mile wide strip of close to very close pack ice lying immediately beyond the fast ice, parallel to the shore and with open water beyond. On New Year's Eve and New Year's Day pack ice visible on horizon (6 miles).	1. 27.0 2. 15.6 3. 21.3
MICHIGAN CITY 28 Dec.- 3 Jan.	Open water to horizon (7 miles) at beginning of the week was followed by the presence of increasing areas of close and very close pack ice extending up to 6 miles from shore on 31 Dec. By 2 Jan. the ice had diminished to a fast ice fringe about 1/2 mile wide and by week's end this fringe had almost disappeared, leaving open water to horizon.	
WILMETTE 28 Dec.- 3 Jan.	Fast ice fringe 100 yards wide present all week. From 28 Dec. through 1 Jan. varying concentrations of pack ice lying to horizon or limit of visibility which varied from 1/2 mile to 4 miles (horizon). On 28 and 29 Dec. there was a shore lead 1/2 to 1 mile wide between fast ice and pack. On 2 and 3 Jan. there was open water to horizon.	

Station	Ice Situation	Temp. °F
MILWAUKEE 28 Dec.- 3 Jan.	Pack ice of varying concentrations present inside harbor breakwaters, with generally more in the northern end of the harbor than the southern. Open water outside the breakwaters all week.	1. 19.6 2. 6.6 3. 12.0
TWO RIVERS 28 Dec.- 3 Jan.	No ice of any sort 28 and 29 Dec. On 30 Dec. 7/10 ice rind covered area up to 3 miles out which had increased by next day to 10/10 coverage up to 5 miles out from shore. This diminished over the next two days to leave a narrow, rotting fast ice fringe and open water to horizon by week's end.	1. 20.0 2. 10.1 3. 15.0
SHEBOYGAN 28 Dec.- 3 Jan.	Fast ice fringe 200+ yards wide present all week. 28 Dec. ice rind formed a coverage of 6/10 up to 3 miles from shore, by the following day ice rind had opened to horizon (6 miles). This coverage slowly diminished through 1 Jan. On 2 and 3 Jan. there was open water to horizon.	
STURGEON BAY CANAL 28 Dec.- 3 Jan.	Fast ice fringe about 200 yards wide lying along the shore with open water to the horizon (11 miles) all week except for small areas of close pack ice lying off the mouth of the Canal from 31 Dec. to 2 Jan.	1. 19.6 2. 7.4 3. 13.5
CALUMET HARBOR 30 Dec.- 3 Jan.	On 30 and 31 Dec. ice rind and young ice was present up to 4 miles from shore. On 1 and 2 Jan. ice was restricted to inside the harbor breakwater. 3 Jan. open water inside harbor and to horizon.	
SEUL CHOIX POINTE 28 Dec.- 3 Jan.	All week fast ice fringed the shoreline to east and west of the Pointe with the bay between the Pointe and Port Inland being filled with very close pack until 1 Jan. Otherwise open water to horizon except on 30 Dec. when close and very close pack covered the waters up to 7 miles from the Pointe with open water beyond.	

ABSTRACT NO. 4, 1964

Summary: The high temperatures beginning with the New Year continued until the last day of this week. There has been no apparent increase in the amount of ice in the lake and there may have been a decrease. However, the low temperatures on the night of 9-10 Jan. produced ice rind at some western shore stations suggesting that there could be a rapid increase if cold calm conditions settle over the lake. Personal observation of the northern end of the lake suggests that it is almost entirely open. Fast ice in Little Bay de Noc north of Gladstone (formed on 25 Dec. 1963) is now 10-13 inches thick.

S. MANITOU I. 4-6 Jan.	No ice visible from observation point overlooking Manitou Passage.
CHARLEVOIX 7-10 Jan.	Open water to horizon (7 miles) all week.

Station	Ice Situation	Temp. °F
FRANKFORT 7 Jan.	Up to 7 Jan. no ice had been seen at this station.	
MANISTEE 4-10 Jan.	No ice, either fast or drifting, all week.	1. 36.1 2. 26.1 3. 31.1
LUDINGTON 4-10 Jan.	Open water to horizon (7 miles) all week. Shore ice restricted to an ice foot.	
MUSKEGON 4-10 Jan.	There has been very little ice all week. Fast ice fringe 100 yards to 300 yards wide with half mile wide strip of close pack lying adjacent to the fast ice. Until 8 Jan. the pack was only seen to the south but on 9 and 10 Jan. had spread all along the coast.	1. 36.1 2. 28.6 3. 32.3
GRAND HAVEN 4-10 Jan.	Fast ice fringe up to 400 yards wide all week. Varying concentrations of pack ice lying adjacent up to 1-1/2 miles out with open water beyond.	
HOLLAND 4-10 Jan.	Fast ice fringe present all week about 200-300 yards wide. Narrow fringe of close pack adjacent to fast ice began to move out on 8 and 9 Jan. before being dramatically blown back producing grounded windrows up to 30 feet high on 10 Jan.	
SOUTH HAVEN 4-10 Jan.	Ice lined the shore all week never extending more than 1 mile off shore. Fast ice fringe reduced to 200 yards wide at week's end with 200-300 yards of pancake ice and brash beyond.	1. 33.8 2. 28.4 3. 31.1
BENTON HARBOR- ST. JOSEPH 4-10 Jan.	Fast ice fringe about 800 yards wide at beginning of week but had decreased to 200 yards at week's end. 4-7 Jan. a strip of close pack about 1 mile wide lay outside the fast ice fringe. 8-9 Jan. close pack just visible on the horizon (6 miles) with open water between. By week's end no ice visible more than a mile from shore.	1. 36.6 2. 28.6 3. 32.6
MICHIGAN CITY 4-10 Jan.	Open water all week.	1. 36.4 2. 28.3 3. 32.3
KENOSHA 4-10 Jan.	Open water all week until last day when young ice formed to horizon overnight and began to drift off shore during the day.	
MILWAUKEE 4-10 Jan.	Open water beyond breakwaters all week. Inside harbor variable amounts of pack ice at northern and southern ends with middle part open.	1. 37.8 2. 25.4 3. 31.6
SHEBOYGAN 4-10 Jan.	Very narrow fast ice fringe all week with open water to horizon (6 miles) until 10 Jan. when 6/10 cover of small floes visible to horizon.	
TWO RIVERS 4-10 Jan.	Apart from a grounded ice fringe (ice foot) no other ice until 10 Jan. when ice rind formed overnight breaking up during the day to give a 7/10 coverage.	1. 35.7 2. 24.1 3. 29.9

Station	Ice Situation	Temp. °F
STURGEON BAY CANAL 4-10 Jan.	Narrow fast ice fringe, much of it probably grounded all week with open water beyond.	1. 36.3 2. 21.7 3. 28.0
MENOMINEE-MARINETTE 4-10 Jan.	Heavy fast ice fringe extending up to 1/2 mile from shore all week. On 4 Jan. open water beyond fast ice to horizon (7 miles). 5 Jan. very close pack to horizon which broke up leaving patches of open pack ice. Ice rind on 8 Jan. to horizon broke up on the 9th and reformed the following day.	1. 31.6 2. 20.7 3. 26.1
PLUM ISLAND 1-10 Jan.	1-5 Jan. open water with narrow ice fringes around island shores. 6 Jan. ice rind formed, breaking up on the following day giving open pack ice through 9 Jan. At week's end island was surrounded with close pack.	
ESCANABA 4-10 Jan.	Fast ice to horizon all week which, at week's end, had reportedly spread almost to Minneapolis Shoal.	
SEUL CHOIX POINTE 4-10 Jan.	Narrow fast ice fringe to east and west of Pointe all week with varying amounts of brash blowing in and out of the bay between the Pointe and Port Inland.	

ABSTRACT NO. 5, 1964

Summary: There has been some increase in the amount of ice which has been most clearly marked at the southern end of the lake. Green Bay is slowly freezing over but apart from the winter ice reported in the middle of the week at Seul Choix Pointe, the northern end of the lake seems mostly open. In the southern end of the lake ice distribution was dominated by strong easterly winds during the first three days of the week. Ice present at the beginning of the week at Muskegon, Grand Haven, Holland and South Haven was blown away while the Indiana and Illinois shorelines were invaded by very close pack ice, driven before the wind, sometimes rafting and consolidating. The main body of the lake is still, presumably, open.

Station	Ice Situation	Temp. °F
MACKINAC ISLAND 1-18 Jan.	Dominant condition: open water all round island with a little ice drifting through the Straits of Mackinac from Lake Michigan to Lake Huron.	
CHARLEVOIX 11-17 Jan.	Dominant condition: open water to horizon all week (8 miles). Lake Charlevoix froze over on 14 Jan. and by week's end was reportedly 5-1/2 inches thick.	
GRAND TRAVERSE LIGHT 11-17 Jan.	Dominant condition: open water to horizon (8 miles). Small amounts of thin fast ice forming in Cat Head and Northport Bays. On 15 and 17 Jan. brash ice visible to horizon but less than 1/10 coverage.	1. 27.1 2. 17.8 3. 22.4
FRANKFORT 11-17 Jan.	No ice observed all week.	

Station	Ice Situation	Temp. °F
MANISTEE 11-17 Jan.	Dominant condition: open water to horizon (6 miles) all week. Narrow ice fringe, 25-150 yards, formed on the 12th but had gone by the 16th.	1. 25.8 2. 15.1 3. 20.4
LUDINGTON 11-17 Jan.	Fast ice fringe along shoreline about 40 ft wide, much of which is probably grounded. Otherwise open water to horizon (7 miles) all week.	1. 23.1 2. 15.3 3. 17.4
MUSKEGON 11-17 Jan.	Dominant condition: open water to horizon (8 miles). On 11 Jan. there was 3/10 coverage almost to horizon of small floes and ice cakes which by 14 Jan. had disappeared leaving only a narrow fringe of fast and/or grounded ice.	1. 26.1 2. 17.8 3. 21.9
GRAND HAVEN 11-17 Jan.	Dominant condition: open water to horizon with narrow fast ice fringe. On 11 Jan. there was 5/10 coverage to horizon (7 miles) which was blown away by the strong E'ly winds of the following two days leaving open water for the remainder of the week.	
HOLLAND 11-17 Jan.	Fast ice fringe present all week about 300 yards wide. Close pack ice present at beginning of week disposed during first three days with generally easterly winds. Open water to horizon (5 miles) from 14 Jan. to week's end.	
SOUTH HAVEN 11-17 Jan.	Fast ice fringe present all week. 11 through 13 Jan. close pack ice visible to horizon with less concentrated ice along the shore--almost a shore lead. Very little drifting ice until end of week when very close pack ice extended up to 3 miles from shore.	1. 23.4 2. 17.9 3. 20.6
BENTON HARBOR-ST. JOSEPH 11-17 Jan.	Fast ice fringe slowly increased during week to about 1/2 mile wide. All week pack ice was visible in varying amounts arranged parallel to the shoreline and only rarely extending more than 5 miles from shore. Thickness of the pack ice estimated at about 6 inches.	1. 24.3 2. 16.4 3. 20.3
MICHIGAN CITY 11-17 Jan.	11 and 12 Jan., no ice. On 13 Jan. ice began to form along shoreline and by the following day there was fast, consolidated ice to the horizon (7 miles). 15 through 17 Jan. the pack ice broke up and diminished leaving a fast ice fringe 100-600 yards wide and an area of drifting very close pack ice off shore surrounded by open water stretching to the horizon.	
CALUMET 11-17 Jan.	Dominant condition: fast ice in Calumet Harbor extending northwards to limit of visibility (5 miles), SE'-wards almost to Indiana Harbor and about 2 miles out from shore. There is open water beyond. With open water at the beginning of the week the fast ice appears to have been formed by ice driven before strong to gale force E'ly winds which rafted it to thicknesses of 1-2 feet.	1. 27.4 2. 16.3 3. 21.8
WILMETTE 11-17 Jan.	Dominant condition: there has been pack ice of varying concentrations to the horizon (4-7 miles) all week. The strong E'ly winds of 11, 12 and 13 Jan. drove ice on shore	1. 28.1 2. 19.6 3. 23.8

Station	Ice Situation	Temp. °F
WILMETTE	and left, by week's end, a strip of consolidated fast ice between 300 yards and 1000 yards wide. The pack ice beyond has varied from open to close concentrations.	
KENOSHA 11-17 Jan.	Only a little ice present during the week, restricted to first four days when fast ice with a fringe of light pack lay within a mile from shore with open water to the horizon beyond (6-7 miles). By 13 Jan. the fast ice had broken up leaving only very open drift ice which had disappeared by 15 Jan. leaving open water to the horizon for the remainder of the week.	
MILWAUKEE 11-17 Jan.	Dominant condition: open water to horizon beyond breakwaters with close or very close pack inside breakwaters except for open water off river mouth. On 13 Jan. a small amount of brash ice lay just outside breakwaters and on the following day there was an indication of drift ice on the horizon (8 miles). On 15 Jan. dominant condition returned.	1. 27.0 2. 12.9 3. 19.9
SHEBOYGAN 11-17 Jan.	The dominant condition during the week was small areas of open pack ice visibly surrounded by open water. The maximum ice coverage was on 12 Jan., 3/10 pack to horizon, and by week's end there was open water to the horizon (6-7 miles) leaving only a narrow fast and/or grounded ice fringe.	
TWO RIVERS 11-17 Jan.	Dominant condition: open water to horizon. On 11, 13 and 14 Jan. there was some brash ice along the shoreline but never extending out more than 1 mile. At week's end there was only a narrow fringe of fast and ground ice.	1. 28.3 2. 16.6 3. 22.4
STURGEON BAY CANAL 11-17 Jan.	Dominant condition: open water to horizon with narrow fast ice fringe. On 12 Jan. young ice formed for about half mile out from the fast ice, broke up on the 13th and on the 14th there was open pack ice to the horizon which had dispersed by the following day.	1. 22.0 2. 11.9 3. 16.9
MENOMINEE-MARINETTE 11-17 Jan.	Fast ice to horizon, formed on 10 Jan. has remained all week. Ice thickness given as 7 inches on 15 Jan.	1. 20.4 2. 10.9 3. 15.6
PLUM ISLAND 11-17 Jan.	Open water surrounded the island from 11 through 13 Jan. while close pack ice invested the island for the remainder of the week.	
ESCANABA 11-17 Jan.	Fast ice to horizon; no change from previous week.	
SEUL CHOIX POINTE 11-17 Jan.	At the beginning of the week there was close pack ice up to 8 miles out from the Pointe. On 13 and 14 Jan. this had consolidated to 10/10 coverage but had completely disappeared leaving open water to the horizon (10 miles) for the rest of the week apart from a small amount of open pack off the Pointe on 16 Jan.	1. 23.0 2. 16.0 3. 19.5

Station	Ice Situation	Temp. °F

ABSTRACT NO. 6, 1964

Summary: This has been a bad week for the Lake Michigan Ice Project! There has been a general decrease in the amount of ice in the lake as a result of persistently above freezing temperatures. The aerial ice survey made by the U. S. Lake Survey (64-M-2) showed that ice was restricted to Green Bay, with small areas of pack ice blocking the Straits of Mackinac and at the southern end of the lake leaving the remainder of the lake open.

Station	Ice Situation	Temp. °F
CHARLEVOIX 18-24 Jan.	Open water to horizon all week.	
FRANKFORT 18-24 Jan.	Open water to horizon all week.	
MANISTEE 18-24 Jan.	Open water to horizon all week. No ice on beach.	1. 44.8 2. 30.3 3. 37.5
LUDINGTON 18-24 Jan.	Open water to horizon all week.	1. 36.6 2. 31.1 3. 33.8
MUSKEGON 18-24 Jan.	Dominant condition: open water to horizon all week. Fast ice fringe 200 yards wide, much reduced by week's end.	1. 37.7 2. 32.1 3. 34.9
GRAND HAVEN 18-24 Jan.	Dominant condition: fast ice along shore with off-lying contiguous area of close to very close pack extending not more than a mile from shore with open water to the horizon (7 miles) beyond. On 22 Jan. very close pack on horizon with intervening shore lead. By week's end narrow fringe of fast ice only.	1. 42.1 2. 36.3 3. 39.2
GRAND TRAVERSE LIGHT 18-24 Jan.	Dominant condition: open water to horizon all week. Narrow ice fringes in Northport and Cat Head Bays disappeared by 20 Jan.	
HOLLAND 18-24 Jan.	Dominant conditions: open water to the horizon all week with narrow fringe of fast ice a few hundred yards wide.	
SOUTH HAVEN 18-24 Jan.	Dominant condition: open water with intermittent small areas of pack ice usually arranged parallel to narrow fast ice fringe. Considerable pack ice present only on 19 Jan. when, beyond a shore lead, there was close pack ice to the horizon.	
BENTON HARBOR-ST. JOSEPH 18-24 Jan.	Dominant condition: open water to the horizon except on first day when there was close pack to the horizon (6 miles). By week's end fast ice fringe melting rapidly.	1. 43.8 2. 30.0 3. 36.9
MICHIGAN CITY 18-24 Jan.	Dominant condition: open water to horizon. On 21 and 22 Jan. small areas of open pack ice drifting close to shore.	1. 42.8 2. 35.6 3. 39.2

Station	Ice Situation	Temp. °F
KENOSHA 18-24 Jan.	Open water to horizon all week.	
MILWAUKEE 18-24 Jan.	Open water to horizon all week outside breakwaters. Some close pack ice in harbor at beginning of week but by the end there was only one small area of fast ice.	1. 44.6 2. 32.1 3. 38.3
SHEBOYGAN 18-24 Jan.	Open water to horizon all week. Narrow fringe of fast ice, much of it probably grounded, present all week.	
STURGEON BAY CANAL 18-24 Jan.	Dominant condition: open water to horizon all week except for small area of open pack off mouth of channel on 19 Jan.	1. 39.6 2. 30.7 3. 35.1
MENOMINEE-MARINETTE 18-24 Jan.	Open water to horizon all week except for a small fringe of fast ice.	1. 35.0 2. 26.1 3. 30.5
PLUM ISLAND 18-24 Jan.	Dominant condition: open water to horizon (6 miles) all week apart from small area of open pack in Detroit Island Passage on 18 and 20 Jan.	
WILMETTE 18-24 Jan.	Dominant condition: open water to horizon all week except for strip of close pack present on 21 Jan. At the beginning of week fast ice fringe was up to 3/4 mile wide but, by week's end, this had reduced to 100-200 yards.	
SEUL CHOIX POINTE 18-24 Jan.	Dominant condition: open water to horizon all week. There has been a fast ice fringe all week and on 19 and 20 Jan. there was a small amount of brash ice to east and west of the Pointe.	1. 37.3 2. 31.3 3. 34.3

ABSTRACT NO. 7, 1964

Summary: There is still very little ice in the lake. Reports from stations around the southern end of the lake indicate the general presence of pack ice about mid-week but it is unlikely that this amounts to very much more than during the previous week. The northern end of the lake appears to be entirely ice free except around the Straits of Mackinac and in Green Bay.

MACKINAC ISLAND 29-31 Jan.	Dominant condition: rotten pack visible around island.	
CHARLEVOIX 25-31 Jan.	No ice visible all week from N. Pier Head. Flights from Charlevoix to Beaver Island on 29, 30 and 31 Jan. showed open water in all directions except for fast ice and open pack extending 5-7 miles out along the shore from Point Patterson to the Straits of Mackinac. Open pack appears to cover the Straits area and connects Waugoshance Point and Hog Island.	

Station	Ice Situation	Temp. °F
GRAND TRAVERSE LIGHT 25-31 Jan.	Dominant condition: open water to horizon all week. Narrow fast ice fringe formed on 26 Jan. and remained for the rest of the week.	1. 31.0 2. 23.3 3. 27.1
FRANKFORT 25-31 Jan.	No ice all week.	
MANISTEE 25-31 Jan.	Dominant condition: open water to horizon. On 28 Jan. a 50-yard wide ice fringe formed along the beach with open pack about 1 mile off shore which had dispersed the following day. By week's end the fast ice fringe had increased to 150 yards wide.	1. 31.3 2. 18.7 3. 25.0
LUDINGTON 25-31 Jan.	Open water to horizon all week.	1. 29.0 2. 20.7 3. 24.8
MUSKEGON 25-31 Jan.	Dominant condition: open water to horizon with fast ice fringe. On 28, 30 and 31 Jan. a narrow fringe of open pack ice lay up to 2 miles off shore.	1. 31.6 2. 21.0 3. 26.3
GRAND HAVEN 25-31 Jan.	Dominant condition: fast ice fringe present all week with mostly open water on the horizon. From 27 Jan. for the remainder of the week varying amounts of close ice lay off shore reaching a maximum coverage of 4 miles from shore on 28 and 29 Jan.	
HOLLAND 25-31 Jan.	Dominant condition: open water to horizon except for a band of close brash ice lying up to a mile beyond the fast ice from 28 Jan. to the end of the week.	
SOUTH HAVEN 25-31 Jan.	Dominant condition: open water to horizon except for belt of very close pack ice which appeared on 29 Jan. and slowly diminished over the next two days. Fast ice fringe present all week.	1. 33.8 2. 23.3 3. 28.5
BENTON HARBOR-ST. JOSEPH 25-31 Jan.	Fast ice fringe all week with open water to horizon for the first four days. On 29 Jan. there was close pack up to 6 miles from shore which had moved away from the shore by week's end but still lay on the horizon.	1. 34.4 2. 23.8 3. 29.1
MICHIGAN CITY 25-31 Jan.	Open water to the horizon at the beginning of the week gave way on 27 Jan. to close pack ice within 5 miles of shore. On the following day this consolidated to the horizon, broke up slowly over 29 and 30 Jan. and had dispersed by week's end.	1. 35.4 2. 23.7 3. 29.5
CALUMET 25-31 Jan.	Open water to horizon all week except for small amount of ice rind present in harbor on 30 Jan. only.	1. 36.0 2. 20.0 3. 28.0
WILMETTE 25-31 Jan.	Dominant condition: open water to horizon (5 miles) with a narrow fringe of fast ice except for open pack to horizon on 27 and 28 Jan.	
KENOSHA 25-31 Jan.	Dominant condition: open water to horizon on first and last days of week but ice to horizon between. On 26 Jan., despite strong westerly winds, ice rind formed close to shore with frazil crystals forming farther out. By 28 Jan. there was consolidated pack to the horizon (6 miles) which slowly dispersed during the next two days.	

Station	Ice Situation	Temp. °F
MILWAUKEE 25-31 Jan.	Open water to horizon all week except for an increase in the amount of close pack ice inside the breakwaters.	1. 36.7 2. 17.7 3. 26.2
SHEBOYGAN 25-31 Jan.	Dominant condition: Open water to horizon (6-7 miles) except for a small amount of very open pack ice within 4 miles of shore on 27 Jan.	
TWO RIVERS 25-31 Jan.	Open water to horizon all week except for very small amount of brash ice close to shore on 28 Jan.	
STURGEON BAY CANAL 25-31 Jan.	Dominant condition: open water to horizon (11 miles) all week. On 29 and 31 Jan. there were small areas of brash ice off the mouth of the canal.	1. 30.1 2. 12.3 3. 21.2
PLUM ISLAND 25-31 Jan.	Dominant condition: fast ice to horizon through Plum Island and Detroit Island Passages formed on 28 Jan. and remained throughout the week. Pack ice consolidating during first two days.	
MENOMINEE-MARINETTE 25-31 Jan.	Dominant condition: fast ice to horizon with small areas of open water included. On 30 Jan. ice broke up leaving open water by week's end.	1. 25.1 2. 10.1 3. 17.6
SEUL CHOIX POINTE 25-31 Jan.	Pack ice around the Pointe, extending to the horizon on 26 Jan., gave way to dominantly open water on 27 Jan. for remainder of week.	

ABSTRACT NO. 8, 1964

Summary: The situation does not seem to have changed much since the last abstract. The small amount of drift ice in the southern end of the lake seems to have concentrated more on the eastern side while pack ice in the northern end of the lake has remained in the Straits of Mackinac area. Fast ice remains in the northern and southern ends of Green Bay while the whole of the rest of the lake is open.

Station	Ice Situation	Temp. °F
MACKINAC ISLAND 1-7 Feb.	Dominant condition: open water to horizon except for some areas of drift ice on 1, 4 and 7 Feb.	
CHARLEVOIX 1-7 Feb.	Open water to horizon from Charlevoix pier head. Daily flights from Charlevoix to Beaver Island from Feb. 2 through 7 showed fast ice along the north shore of the lake eastwards from Point Patterson and fast ice between Hog Island and Waugoshance Point with pack covering the water between the fast ice areas. Otherwise there was open water in all directions.	
GRAND TRAVERSE LIGHT 1-7 Feb.	Open water to horizon all week with a narrow fast ice fringe.	1. 34.6 2. 25.1 3. 29.8
FRANKFORT 1-7 Feb.	Open water to horizon all week.	

Station	Ice Situation	Temp. °F
MANISTEE 1-7 Feb.	Open water to horizon beyond a fast ice fringe which narrowed slightly to 50 yards by week's end.	1. 41.1 2. 24.3 3. 32.7
MUSKEGON 1-7 Feb.	Dominant condition: open water to horizon beyond a fast ice fringe except on 2, 3 and 6 Feb. when a band of open pack 1-3 miles wide lay beyond the fast ice.	1. 36.0 2. 26.7 3. 31.3
GRAND HAVEN 1-7 Feb.	Dominant condition: open water beyond a fast ice fringe and varying amounts of pack ice up to 1-3 miles from shore.	
HOLLAND 1-7 Feb.	Open water to horizon (5 miles) for first three days and on last day of week. On 4 Feb. there was close pack to the horizon which dispersed during the following two days.	
SOUTH HAVEN 1-7 Feb.	Dominant condition: open water to horizon (6 miles) beyond a fringe of fast ice or very close pack up to a mile from shore. On 3 Feb. close pack visible near horizon.	1. 33.8 2. 27.6 3. 30.7
BENTON HARBOR- ST. JOSEPH 1-7 Feb.	Dominant condition: varying amounts of pack ice beyond a fast ice fringe. At beginning of week there was close pack up to 5 miles from shore which slowly dispersed from 3 Feb. until the end of the week leaving open water.	1. 37.7 2. 28.6 3. 33.1
MICHIGAN CITY 1-7 Feb.	Open water on first two days and last day of week. Pack ice drifted in on 3 Feb. and consolidated on the 4th dispersing over the following two days leaving a fast ice fringe.	1. 37.3 2. 29.1 3. 33.2
CALUMET 1-7 Feb.	Open water to the horizon all week. (5 miles)	1. 38.6 2. 27.0 3. 32.8
WILMETTE 1-7 Feb.	Open water to horizon all week.	1. 39.3 2. 30.4 3. 34.8
KENOSHA	Open water to horizon all week.	
MILWAUKEE 1-7 Feb.	Open water to horizon all week with some pack inside breakwaters.	1. 41.4 2. 26.7 3. 34.0
SHEBOYGAN 1-7 Feb.	Open water to horizon all week.	
TWO RIVERS 1-7 Feb.	Open water to horizon all week (8 miles).	1. 37.8 2. 27.1 3. 32.4
STURGEON BAY CANAL 1-7 Feb.	Open water to horizon all week with narrow fast ice fringe.	1. 36.4 2. 22.0 3. 29.2
MENOMINEE- MARINETTE 1-7 Feb.	Dominant condition: open water to horizon (7 miles) except on 3 and 4 Feb. when young fast ice covered area, breaking up on 6 Feb.	1. 33.3 2. 22.6 3. 27.9
PLUM ISLAND 1-7 Feb.	Dominant condition: fast ice at beginning of week in Plum Island and Detroit Island Passages; on 3 Feb. open	

Station	Ice Situation	Temp. °F
PLUM ISLAND	water formed around Island and slowly extended eastwards and westwards, until by week's end open water extended through the passages leaving broad fast ice fringes to north and south.	
ESCANABA 1-7 Feb.	Fast ice to horizon all week.	1. 24.0 2. 19.7 3. 21.8
SEUL CHOIX POINTE 1-7 Feb.	Dominant condition: open water to horizon (10 miles) except on 2 and 3 Feb. when young ice extended up to 5 miles from shore. Fast ice fringe present all week and young ice in the bay between the Pointe and Port Inland.	1. 34.1 2. 24.7 3. 29.4

ABSTRACT NO. 9, 1964

Summary: Colder temperatures in the first half of the week appear to have resulted in a slight increase in the amount of ice seen from shore stations south of a line joining Muskegon and Kenosha. There has also been an increase west of the Straits of Mackinac. By the end of the week, with warmer temperatures, much of this increase has probably been dissipated.

Station	Ice Situation	Temp. °F
MACKINAC ISLAND 8-14 Feb.	Small areas of drifting ice passing the island and through the Straits.	
CHARLEVOIX 8-14 Feb.	Dominant condition: open water to horizon (8 miles) except for ice rind to the horizon on 10 Feb. which had dispersed by the following day. Flights from Charlevoix to Beaver Island on 10 through 14 Feb. showed fast ice and pack ice slowly increasing until, by week's end, there was fast ice east of a line from Waugoshance Point to Point Patterson, with pack ice lying between the fast ice and a line connecting Point Patterson, NE point of Beaver Island and Petoskey.	
GRAND TRAVERSE LIGHT 8-14 Feb.	Open water to horizon all week. Narrow fringe of fast ice in Cat Head Bay diminished by week's end.	1. 28.6 2. 22.4 3. 25.5
MANISTEE 8-14 Feb.	Dominant condition: open water to horizon except for a small amount of very open pack on 9 and 10 Feb. within 1 mile of shore.	1. 36.6 2. 21.7 3. 29.1
LUDINGTON 8-14 Feb.	Open water to horizon all week with fast ice fringe about 40 ft wide.	
MUSKEGON 8-14 Feb.	Dominant condition: open water to horizon all week apart from a 5 mile wide fringe of open pack on 9 Feb.	1. 31.3 2. 23.1 3. 27.2
GRAND HAVEN 8-14 Feb.	Dominant condition: open water to horizon with narrow fringe of very close pack lying beyond.	1. 36.0 2. 21.8 3. 28.9

Station	Ice Situation	Temp. °F
HOLLAND 8-14 Feb.	Dominant condition: open water to horizon beyond a fringe of fast ice. Drift ice was visible on the horizon on 11 Feb. which moved in to the shore the following day, lying up to one mile from shore on the 12th and 13th.	
SOUTH HAVEN 8-14 Feb.	Dominant condition: pack ice of varying concentrations lay beyond a fringe of fast ice. Concentration reached a maximum on 13 Feb. when there was close pack to the horizon. This gave way on the 14th to a half mile wide fringe of very close pack beyond the narrow fast ice fringe.	1. 29.1 2. 21.0 3. 25.0
BENTON HARBOR- ST. JOSEPH 8-14 Feb.	Dominant condition: varying amounts of pack ice, usually close to very close lay to the horizon beyond a fast ice fringe. By week's end there was a 1-2 mile wide fringe of very close pack beyond the fast ice.	1. 34.0 2. 23.7 3. 28.8
MICHIGAN CITY 8-14 Feb.	Dominant condition: ice in varying amounts to the horizon (7 miles). Open water on 8 Feb. gave way the following day to close pack ice off shore which became fast to horizon on the 10th. This fast ice remained through 13 Feb. with a shore lead forming and closing on the 12th. At week's end there was open water to horizon again.	1. 32.0 2. 22.7 3. 27.3
WILMETTE 8-14 Feb.	Dominant conditions: open water for the first three days of the week was followed by very close pack up to 4 miles from shore which slowly diminished during the remainder of the week.	1. 32.0 2. 25.7 3. 28.8
KENOSHA 8-14 Feb.	Dominant condition: open pack in small drifting fields. Open water to horizon at the beginning and end of the week with maximum amount of ice on 11 Feb.	
MILWAUKEE 8-14 Feb.	Open water to horizon all week except for varying amounts of pack ice in harbor.	1. 32.7 2. 19.6 3. 26.1
SHEBOYGAN 8-14 Feb.	Dominant condition: open water to horizon except for insignificant areas of brash on 11 and 14 Feb.	
TWO RIVERS 8-14 Feb.	Dominant condition: open water to horizon apart from a very narrow fringe of slushy brash along the shore on 10 Feb.	1. 33.7 2. 18.8 3. 26.2
STURGEON BAY CANAL 8-14 Feb.	Dominant condition: open water to horizon (11 miles). On 9, 10 and 14 Feb. there was a close coverage of ice rind.	1. 33.1 2. 16.7 3. 24.9
PLUM ISLAND 8-14 Feb.	Dominant condition: open water in Plum Island and Detroit Island Passages with occasional fields of drift ice.	
SEUL CHOIX POINTE 8-14 Feb.	Dominant condition: open water to horizon. On 9 through 11 Feb. pack lay off the Pointe reaching a maximum on the 10th (close pack to horizon).	1. 27.1 2. 19.7 3. 23.4

ABSTRACT NO. 10, 1964

Summary: Mean temperatures for this week were some 3F above last week. Ice in the southern end of the lake is decreasing and may be expected to disappear within the next week or two. Fast ice in the Little and Big Bays de Noc varies between 14" and 20" thick. From personal observation on 21 Feb., the fast ice, reported last week in the Straits of Mackinac area, has broken up producing very close pack ice from about Naubinway eastwards to the Straits.

Station	Ice Situation	Temp. °F
MACKINAC ISLAND 15-21 Feb.	Dominant condition: open water with small areas of close pack dispersing eastwards into Lake Huron from the Straits of Mackinac.	
CHARLEVOIX 15-21 Feb.	Dominant condition: open water to horizon except on 21 Feb. when very close pack ice lay along the shore up to 2 miles out.	
GRAND TRAVERSE LIGHT 15-21 Feb.	Dominant condition: open water to horizon except on 21 Feb. when a small area of close pack ice lay up to 4 miles east of the light, across the mouth of Grand Traverse Bay.	1. 32.8 2. 22.4 3. 27.6
MANISTEE 15-21 Feb.	Open water to horizon all week beyond a fast ice fringe 200-300 yards wide.	
MUSKEGON 15-21 Feb.	Dominant condition: open water to horizon beyond a fringe of fast ice, except for open pack up to 5 miles from shore on 19 Feb.	1. 32.6 2. 28.3 3. 30.4
GRAND HAVEN 15-21 Feb.	Dominant condition: open water to horizon beyond a narrow fringe of fast ice and very close pack. Very open pack lay off shore up to 4 miles out on 16 Feb.	
HOLLAND 15-21 Feb.	Dominant conditions: close pack to horizon through 19 Feb. followed by open water for the rest of the week.	
SOUTH HAVEN 15-21 Feb.	Dominant conditions: open water to horizon, with varying amounts of pack ice and/or fast ice lying within one or two miles of shore. On 19 Feb. the situation was temporarily reversed with close pack on the horizon and open water up to the shoreline.	1. 32.0 2. 24.3 3. 28.1
BENTON HARBOR-ST. JOSEPH 15-21 Feb.	Dominant condition: open water to horizon with varying amounts of pack ice and/or fast ice lying within 1 or 2 miles of the shore. On 18 Feb. there was very close pack ice up to 4 miles from shore.	1. 37.0 2. 25.8 3. 31.4
MICHIGAN CITY 15-21 Feb.	Dominant condition: open water to horizon beyond a narrow fast ice fringe except for close pack ice present on 15 and 17 Feb.	1. 35.4 2. 28.8 3. 32.2
CALUMET 15-21 Feb.	Open water to horizon all week.	1. 34.0 2. 27.0 3. 30.5
KENOSHA 15-21 Feb.	Dominant condition: open water to horizon. Some very open pack ice present 4-6 miles from shore on 16 Feb.	

Station	Ice Situation	Temp. °F
MILWAUKEE 15-21 Feb.	Open water to horizon all week. A small amount of pack ice inside the breakwaters during the first three days of the week only.	1. 35.1 2. 22.0 3. 28.5
SHEBOYGAN 15-21 Feb.	Dominant condition: open water to horizon all week apart from very small amounts of brash ice on 18 and 21 Feb.	
TWO RIVERS 15-21 Feb.	Open water to the horizon all week.	1. 34.3 2. 23.0 3. 28.6
STURGEON BAY CANAL 15-21 Feb.	Dominant condition: open water to horizon beyond a narrow fast ice fringe. Small strip of open pack lying off shore on 21 Feb.	1. 36.3 2. 22.1 3. 29.2
MENOMINEE-MARINETTE 15-21 Feb.	Dominant condition: open water beyond a fringe of fast ice. On 18 and 21 Feb. a cover of ice rind formed.	1. 30.6 2. 20.3 3. 25.4
SEUL CHOIX POINTE 15-21 Feb.	Dominant condition: open water to horizon beyond a fast ice fringe. Ice rind formed in the bay between the Pointe and Port Inland and on 21 Feb. there was open pack up to 2 miles from the shore.	1. 34.6 2. 22.0 3. 28.3

ABSTRACT NO. 11, 1964

Summary: There has been very little change from last week. There is still fast ice in the upper and lower parts of Green Bay, consolidated pack west of the Straits of Mackinac and small amounts of pack ice normally concentrated in the southeast corner of the lake. Otherwise, all seems to be open.

MACKINAC ISLAND 22-28 Feb.	Dominant condition: pack ice to west of Island with open water to the east. For the last 3 days of the week the ice to the west consolidated and became fast.
CHARLEVOIX 22-28 Feb.	Dominant condition: open water to the horizon. On 22 and 24 Feb. pack visible along shore. Flights from Charlevoix to Beaver Island on 24 through 28 Feb. showed consolidated or very close pack east of an approximate line joining Harbor Springs and Patterson Point.
GRAND TRAVERSE LIGHT 22-28 Feb.	Open water to horizon all week apart from small amounts of close pack in Cat Head Bay.
FRANKFORT 22-28 Feb.	Open water to horizon all week.
MANISTEE 22-28 Feb.	Open water to horizon all week. Narrow fringe of grounded ice along shore.
LUDINGTON 22-28 Feb.	Open water to horizon all week with a narrow fringe of fast ice usually increasing at night and breaking up during the day.
MUSKEGON 22-28 Feb.	Open water to horizon all week apart from a narrow fast ice fringe.

Station	Ice Situation
GRAND HAVEN 22-28 Feb.	Dominant condition: open water to horizon apart from a narrow strip of fast along the shore, with a half-mile wide fringe of close pack beyond the fast ice.
HOLLAND 22-28 Feb.	Dominant condition: open water to horizon except for fringes of fast ice and pack reaching a maximum of 2-3 miles wide strip of close pack on 28 Feb.
SOUTH HAVEN 22-28 Feb.	Dominant condition: open water to horizon with varying fringes of fast ice and close pack from 1 to 4 miles wide.
BENTON HARBOR-ST. JOSEPH 22-28 Feb.	Dominant condition: fast ice fringe with close pack to horizon (6 miles) except on 27 and 28 Feb. when pack ice fringe was 2 miles wide.
MICHIGAN CITY 22-28 Feb.	Dominant condition: open water with varying amounts of pack ice. Maximum amount of ice on 27 Feb. with fast ice to horizon which had broken up by the following day producing close pack.
CALUMET 22-28 Feb.	Open water to horizon all week except for young ice forming inside harbor breakwater on 26 and 27 Feb.
WILMETTE 22-28 Feb.	Open water to horizon all week.
KENOSHA 22-28 Feb.	Dominant condition: open water to horizon except for areas of close pack on horizon (6 miles) on 26 and 27 Feb. with a fringe of brash ice along the shore.
MILWAUKEE 22-28 Feb.	Open water to horizon all week with varying concentrations of pack ice inside breakwaters.
SHEBOYGAN 22-28 Feb.	Dominant condition: open water to horizon except for open pack on horizon on 22 Feb. with a narrow fast ice fringe all week.
STURGEON BAY CANAL 22-28 Feb.	Dominant conditions: open water with small amounts of brash ice lying close to shore 22 through 25 Feb. Ice rind visible to horizon on 24 Feb. with open pack to horizon on 26 and 27 Feb. Open water to horizon on last day of week.
PLUM ISLAND 22-28 Feb.	Open pack in Plum Island and Detroit Island passages all week.
MENOMINEE-MARINETTE 22-28 Feb.	Young ice present on 24 and 27 Feb.; otherwise there was open water to horizon.
ESCANABA 22-28 Feb.	Fast Ice to horizon all week.
SEUL CHOIX POINTE 22-28 Feb.	Dominant condition: open water to horizon except for large areas of open pack and close pack on 26 and 27 Feb., respectively.

ABSTRACT NO. 12, 1964

Summary: Conditions appear to be much the same as last week. There is still some ice concentrated in the southeastern corner of the lake but it appears to have decreased considerably since last week.

Station	Ice Situation
	Apart from fast ice in parts of Green Bay and very close pack ice west of the Straits of Mackinac, the remainder of the lake is open.
S. MANITOU I. 29 Feb.-6 Mar.	No ice up to 2 Mar. apart from a small amount of ice along the shores of the island.
CHARLEVOIX 29 Feb.-6 Mar.	Dominant condition: open water to horizon except on 6 Mar. when there was open pack to horizon.
GRAND TRAVERSE LIGHT 29 Feb.-6 Mar.	Open water to horizon all week.
FRANKFORT 29 Feb.-6 Mar.	Open water to horizon all week.
MANISTEE 29 Feb.-6 Mar.	Open water to horizon all week.
LUDINGTON 29 Feb.-6 Mar.	Open water to horizon all week.
MUSKEGON 29 Feb.-6 Mar.	Dominant condition: open water to horizon apart from 2 mile wide fringe of open pack on 3 Mar.
GRAND HAVEN 29 Feb.-6 Mar.	Dominant condition: fast ice fringe with 1/2 to 1 mile wide strip of close pack lying up against the fast ice.
HOLLAND 29 Feb.-6 Mar.	Dominant condition: open water to horizon apart from a 3 mile wide fringe of close pack on the first day of the week which had disappeared by 2 Mar.
SOUTH HAVEN 29 Feb.-6 Mar.	Open water to horizon beyond a fast ice fringe up to 1/2 mile wide.
BENTON HARBOR-ST. JOSEPH 29 Feb.-6 Mar.	Dominant condition: fast ice fringe with close to open pack beyond. By week's end there was only a very open coverage of brash ice.
MICHIGAN CITY 29 Feb.-6 Mar.	Consolidated pack ice to horizon on first day of week gave way to open water to horizon for the remainder of the week.
WILMETTE 29 Feb.-6 Mar.	Open water to horizon all week.
MILWAUKEE 29 Feb.-6 Mar.	Open water to horizon all week. By 3 Mar. all the pack ice had gone from inside the breakwaters.
SHEBOYGAN 29 Feb.-6 Mar.	Open water to horizon beyond a narrow fast ice fringe, probably grounded.
TWO RIVERS 29 Feb.-6 Mar.	Open water to horizon all week.
STURGEON BAY CANAL 29 Feb.-6 Mar.	Open water to horizon all week.
PLUM ISLAND 29 Feb.-6 Mar.	Open pack around the island for the first three days of the week gave way to open water until the last day when close pack filled both passages round the island.

Station	Ice Situation
ESCANABA 29 Feb.-6 Mar.	Fast ice to horizon all week.
SEUL CHOIX POINTE 29 Feb.-6 Mar.	Dominant condition: open water to horizon except on last day of week when there was open pack up to 6 miles from the Pointe.

ABSTRACT NO. 13, 1964

Summary: Apart from the ice in Green Bay, now broken up by the U.S.C.G. Cutters Mackinaw and Mesquite, and the ice west of the Straits of Mackinac the remainder of the lake appears now to be entirely open. The small fast ice fringes on the eastern shore of the lake are almost certainly grounded and of no navigational consequence. Observations have now been discontinued at Michigan City, Calumet Harbor, Wilmette, Kenosha, Milwaukee, Sheboygan and Two Rivers.

CHARLEVOIX 8-13 Mar.	Dominant condition: open water to horizon. On 7 Mar. open pack was visible to horizon. On 12 Mar. there was close pack lying in a mile wide strip against the shore. Flights from Charlevoix to Beaver Island on 9 through 13 Mar. showed open to close pack extending into the Straits of Mackinac from a line joining Patterson Point and Beaver Island. On 9 Mar. there were considerable areas of open pack between the Fox Island, Beaver Island and the mainland. By week's end this was much reduced.
GRAND TRAVERSE LIGHT 8-13 Mar.	Open water to horizon all week.
MANISTEE 8-13 Mar.	Open water to horizon all week apart from narrow grounded ice fringe.
MUSKEGON 8-13 Mar.	Open water to horizon all week apart from narrow grounded fast ice fringe.
GRAND HAVEN 8-13 Mar.	Dominant condition: open water to horizon apart from a narrow strip of close pack lying off shore for the first two days of the week.
HOLLAND 8-13 Mar.	Dominant condition: open water to horizon apart from very open pack on 8 and 9 Mar. which consolidated against the shore on 10 Mar. The ice was coming the L. Macatawa and by week's end all ice had disappeared.
SOUTH HAVEN 8-13 Mar.	Dominant condition: open water to horizon apart from a narrow fringe of grounded ice and a strip of brash lying off shore on 8 Mar. By week's end there was no ice.
BENTON HARBOR-ST. JOSEPH 8-13 Mar.	Open water to horizon all week apart from a narrow grounded ice fringe 10-30 yards wide.
MICHIGAN CITY 8-13 Mar.	Open water to horizon all week.

Station	Ice Situation
CALUMET HARBOR 8-13 Mar.	Open water to horizon all week.
WILMETTE 8-13 Mar.	Open water to horizon all week.
KENOSHA 8-13 Mar.	Open water to horizon all week.
MILWAUKEE 8-13 Mar.	Open water to horizon all week.
SHEBOYGAN 8-13 Mar.	Open water to horizon all week.
TWO RIVERS 8-13 Mar.	Open water to horizon all week.
STURGEON BAY CANAL 8-13 Mar.	Open water to horizon all week apart from a narrow fast ice fringe, probably grounded.
MENOMINEE-MARINETTE 8-13 Mar.	Dominant condition: open water beyond a fringe of fast ice. On 9 through 11 Mar. there was open pack ice to the horizon.
ESCANABA 8-13 Mar.	Fast ice to horizon until 11 Mar. when U.S.C.G.C. Mackinaw broke up ice in the shipping channel up to Gladstone.
SEUL CHOIX POINTE 8-13 Mar.	Dominant condition: open water to the horizon. There were some fluctuations in the amount of ice in the bay east of the Pointe and a little ice rind formed overnight on 11 Mar.

ABSTRACT NO. 14, 1964

Summary: The lake is now entirely ice free apart from some ice remaining west of the Straits of Mackinac and in parts of Green Bay. The low temperatures in the northern parts of the lake during the week probably helped in the persistence of these ice areas.

Observations have now been discontinued at all stations except Mackinac Island, Charlevoix, Menominee, Plum Island, Escanaba, and Seul Choix Pointe.

CHARLEVOIX 14-20 Mar.	Open water to the horizon all week. Flights from Charlevoix to Beaver Island on 15, 16, 18-20 Mar. show open pack east of line roughly joining Naubinway with Garden Island and Cross Village. There appears to have been a slight increase in the amount of ice during the week.
GRAND TRAVERSE LIGHT 14-20 Mar.	Open water to horizon all week.
MANISTEE 14-20 Mar.	Open water to horizon all week.
MUSKEGON 14-20 Mar.	Open water to horizon all week.

Station	Ice Situation
GRAND HAVEN 14-20 Mar.	Open water to horizon all week.
HOLLAND 14-20 Mar.	Open water to horizon all week.
BENTON HARBOR-ST. JOSEPH 14-20 Mar.	Open water to horizon all week.
STURGEON BAY CANAL 14-20 Mar.	Open water to horizon all week.
MENOMINEE-MARINETTE 14-20 Mar.	A little fast ice remaining to north and south of station throughout week. On 20 Mar. ice rind formed up to 4 miles from shore but subsequently broke up. Fast ice fringe with open water beyond until 19 and 20 Mar. when open pack lay off the Pointe up to 5 miles out.

ABSTRACT NO. 15, 1964

Summary: The only remaining ice is in Green Bay and west of the Straits of Mackinac. In both areas the ice is breaking up and dispersing. On 29 Mar. 3 cargo boats were seen passing through the Straits with little apparent difficulty.

CHARLEVOIX 21-27 Mar.	Open water to horizon all week. Flights from Charlevoix to Beaver Island on 22 through 27 Mar. showed varying arrangements of open and close pack ice east of a line joining Patterson Point and Beaver Island with areas of fast ice in Sturgeon Bay and Little Traverse Bay.
STURGEON BAY CANAL 21-27 Mar.	Open water to horizon all week except for strip of close pack up to 5 miles wide lying off shore on 27 Mar.
MENOMINEE-MARINETTE 21-27 Mar.	Dominant condition: open water to horizon. On 21 and 22 Mar. there was open pack which gave way to open water conditions until the last day of the week when open pack again covered the area.
ESCANABA 21-27 Mar.	Following ice breaking activities by U.S.C.G.C. Mackinaw on 11/12 Mar. the ice drifted southwards out of the bay between 28 and 30 Mar. leaving only a continuous fringe of fast ice around the bay.
SEUL CHOIX POINTE 21-27 Mar.	Dominant condition: open water to horizon except for small areas of very open pack near the Pointe on 21, 24 and 27 Mar.

ABSTRACT NO. 16, 1964

Final Report

Summary: The last ice on the lake has been slow to pass away. At the end of March there was little ice remaining except shore fast fringe areas in Green Bay and towards the Straits of Mackinac. On

Station	Ice Situation
	10 Apr. the Lake Survey aerial reconnaissance (64-M-3) showed some ice against the western shore of the Door Peninsula, some in Big Bay de Noc and some around the Straits of Mackinac. On 15 Apr. the Beaver Island flight from Charlevoix reported open water in all directions. This would appear to mark the final phase of the 1963-64 ice season in Lake Michigan.
CHARLEVOIX 28 Mar.-15 Apr.	During the week beginning 28 Mar. there was a slow build-up of ice until on 3 Apr. there was 6 to 8 miles of consolidated and moderately windrowed ice off shore. Between 4 and 10 Apr. there were half-mile fringes of rotting pack from time to time and since 10 Apr. there has been open water.
STURGEON BAY CANAL 28 Mar.-15 Apr.	The only ice present, a narrow fast ice fringe, probably grounded, had gone by 1 Apr., since when there has been open water to the horizon.
MENOMINEE-MARINETTE 28 Mar.-15 Apr.	Fast ice fringes to north and south of the river mouth remained until 7 Apr. since when there has been open water to the horizon.
ESCANABA 28 Mar.-15 Apr.	After opening of Little Bay de Noc by U.S.C.G.C. Mackinaw on 11 Mar., the ice remained unchanged until strong north winds on 28 through 30 Mar. reduced it to a substantial shore fast fringe. This slowly diminished until 8 Apr. when there was no ice left.
SEUL CHOIX POINTE 28 Mar.-3 Apr.	Open water to horizon on 28 Mar. changed to open pack to horizon on 29 Mar. which had gone by 30 Mar. There was some very scattered ice, less than 1/10 cover, on 1 Apr. since when there has been open water to the horizon apart from a very narrow grounded ice fringe.

APPENDIX C

UNITED STATES DEPARTMENT OF COMMERCE

WEATHER BUREAU

INSTRUCTIONS FOR COMPLETION OF SHORE-BASED ICE OBSERVATION DATA SHEETS

U. S. Weather Bureau
Old Administration Building
Metropolitan Airport, Michigan

August 1964

(This memorandum supercedes similar instructions, dated November 1963, distributed from the University of Michigan.)

INSTRUCTIONS FOR COMPLETION OF SHORE-BASED ICE OBSERVATION DATA SHEETS

1. INTRODUCTION

The United States Coast Guard, 9th District, cooperating with the U. S. Weather Bureau, is supporting the shore-based ice observation program at 22 Coast Guard stations around Lake Michigan. This program is a continuation of the system of ice observation on Lake Michigan arranged by Dr. John A. Heap of the University of Michigan for the 1963-64 season. These instructions are similar in outline to those dated November 1963 but include various small changes as a result of experience during the first season of operations. They mainly concern a reduction in the amount of meteorological data required and an increased differentiation in the types of fast ice. The object of the program is to obtain a daily record of the ice conditions within view of each station throughout the ice season. In particular, information is required on the formation of ice, extent of fast ice, concentration of pack ice (drift ice), and the melting, break-up and final dispersal of the ice in the spring. Maps are provided for recording observations because it is easier and more accurate to complete a map than to try to describe in words a complex pattern of ice distribution.

The shore-based observation program is an essential part of a study of the formation, growth, movement and decay of ice in the Great Lakes, which also includes aerial observations and measurements of ice thickness and ice drift. The long term purpose of the study is to achieve reliable methods of forecasting the formation, growth, decay and movement of ice.

A list of useful terms and their definitions will be found at the end of these instructions.

2. METHODS OF OBSERVING

1. Observations should be started on the day that the first ice is seen and should continue until the last ice is seen.
2. Observations should be made from the highest convenient point above the lake surface so that the maximum field of view is obtained.
3. Observations should be made daily from the same point and at the same time. If the weather does not permit an observation at the usual hour, it is better to make one at some other time rather than miss that day altogether.

4. When at the observation point it will be found most convenient to observe in the following order:

   A) Note range of visibility.
   B) If there is any fast ice present, plot its outer edge.
   C) If there is pack ice present, plot areas of approximately equal concentration and mark the number of tenths concentration in each area.
   D) Mark on each area of similar concentration the average size of the constituent ice floes.
   E) If possible, estimate the thickness of the pack ice.
   F) Note signs of pressure or decay.
   G) On returning to the station, note the wind direction and speed.

The following are notes in expansion of items A through G:

A) Visibility: Visibility is primarily limited by the height of the observer above the lake surface and may be further limited by weather conditions. At the foot of each observation map will be found a list of the distances to the horizon from various heights above the water level. Having ascertained the height of your normal observation point above the lake, make a mental note of how far you can see over the lake. (Note that each map is marked with concentric rings one mile apart.) Only abnormal refraction conditions will alter the range of visibility by producing mirages of conditions beyond the horizon. In the place reserved for entering visibility conditions it is only intended that a note should be made if the normal visibility to the horizon is restricted by weather conditions such as fog, frost smoke, falling or driven snow.

B) Fast Ice. Definition: Ice which remains fast, generally in the position where originally formed, and which may attain considerable thickness. It is afloat and is found along coasts where it is attached to the shore, or over shoals.

Frequently the fast ice will be a mere strip a few yards wide along the shore. In this case draw a solid pencil line along the shoreline and label it "fast ice fringe." Give an estimate of its average width, e.g., "fast ice fringe 40 yards wide" or "200-300 yards wide." If it is more than half a mile wide it should be possible to indicate its extent on the map.

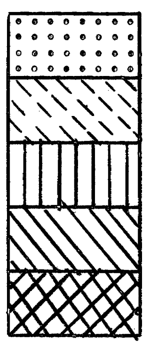
Ice foot. Definition: Ice attached to the coast and aground, unmoved by tides (seiches) or waves and remaining after the fast ice has moved away.

Along gently shelving sandy shores an ice foot will often be present. The essential characteristic is that it is aground and will remain in position when fast ice or pack ice has drifted out. It is built up by wind action, pressure, waves and freezing spray and will only be removed by slow melting

or physical destruction by storm waves. It is usually the last remnant of ice at the end of the season. Because it is not subject to the same controlling factors as floating ice--either fast ice or pack ice--it is essential to distinguish the presence of an ice foot on the maps. Simple inspection with a 6-foot pole to sound the water at the edge of the supposed ice foot will show whether it is aground or not.

It can be safely assumed that if fast ice is present there will also be an ice foot, perhaps very small, and there is no need to write anything further on the chart than is directed under the heading for <u>fast ice</u> above. *If, however, in your judgment, there is a firmly grounded ice foot with open water or pack ice beyond then draw a bold dotted line along the coast and label it ICE FOOT.*

C) <u>Ice concentration</u>: Since it is not possible to plot each individual ice floe, it is normal practice in ice reconnaissance to show areas in which the concentration of ice is approximately the same. (See example map.) The categories of ice concentration as used by the U. S. Hydrographic Office are as follows:



less than 1/10 coverage - open water

1/10 to 5/10 coverage - open pack ice

5/10 to 8/10 coverage - close pack ice

8/10 to 10/10 coverage - very close pack ice

10/10 coverage (no water) - consolidated pack ice or fast ice

Draw on the map lines which mark the boundaries of the various ice concentrations, mark them with the appropriate shading or hatching and label them with the concentration in tenths cover, size of floes and thickness (see following two sections).

D) <u>Size of ice floes</u>: The size of constituent ice floes in pack ice bears an important relationship to the potential navigability of the ice. Therefore it is necessary to know the approximate average size of the floes. The following are the most widely used categories of size:

Brash ice	less than 2 yards across
Ice cake	2-10 yards across
Small floes	10-200 yards across
Medium floes	200-1000 yards across
Big floes	1000 yards-6 miles across
Vast floes	more than 6 miles across

Mark the average size of the constituent ice floes in each area of similar concentration, e.g., "6/10ths small."

E) Ice thickness: An estimate of the thickness of pack ice in the lake should be given. It is difficult to make this estimate accurately and the only guide that can be given is that between 1/10 and 2/10 of the total thickness shows above the water level, i.e., if one inch shows above the surface, the total thickness will be between 5 and 10 inches. The normal density of lake ice is about 0.9 implying that only 1/10 will show above the surface with 9/10 below; however a snow cover can increase the apparent thickness above the surface without increasing the total thickness by the proportion of 1 to 9. *As a convention, describe ice which you estimate is less than one foot thick as LIGHT and ice more than one foot thick as HEAVY.* When describing light, thin ice note that the terms ICE RIND and YOUNG ICE are useful (see definitions on p. 51).

F) Pressure: The two most obvious results of pressure in ice are rafting and hummocking. Both are the result of ice, driven by the wind, meeting the coastline or another ice sheet. Rafting, a process similar to pushing together a deck of splayed out playing cards, results in a rapid increase in ice thickness. It is more usually observed in thin ice less than about 6 inches thick, but is occasionally found in much thicker ice. Sufficiently severe pressure to produce windrows (pressure ridges) is most frequently exerted against the shoreline of the lake and results in an ice foot. On the scale of the maps provided the exact location of a windrow, etc., cannot be marked, but the following symbols can be used to indicate that pressure phenomena are present:

 Rafting

 Windrows

Decay: The first signs of the spring decay of ice will be an increasing greyness of the hitherto white snow surface. As the snow on top of the ice melts, the slight irregularities in the ice surface will concentrate the slushy melt water giving a mottled appearance to the ice. After heavy rain, or an unseasonably hot day, the darker areas may turn into puddles. Once the ice is well rotted the wave action and increased water turbulence in a storm can dissipate and melt the ice very quickly. Symbols are:

Rotting Ice . . Rn
Puddles . . . . Pd

(Note that a grey tone can also be given to the ice by waves breaking over the edge of the ice and flooding the surface at any time during the ice season.)

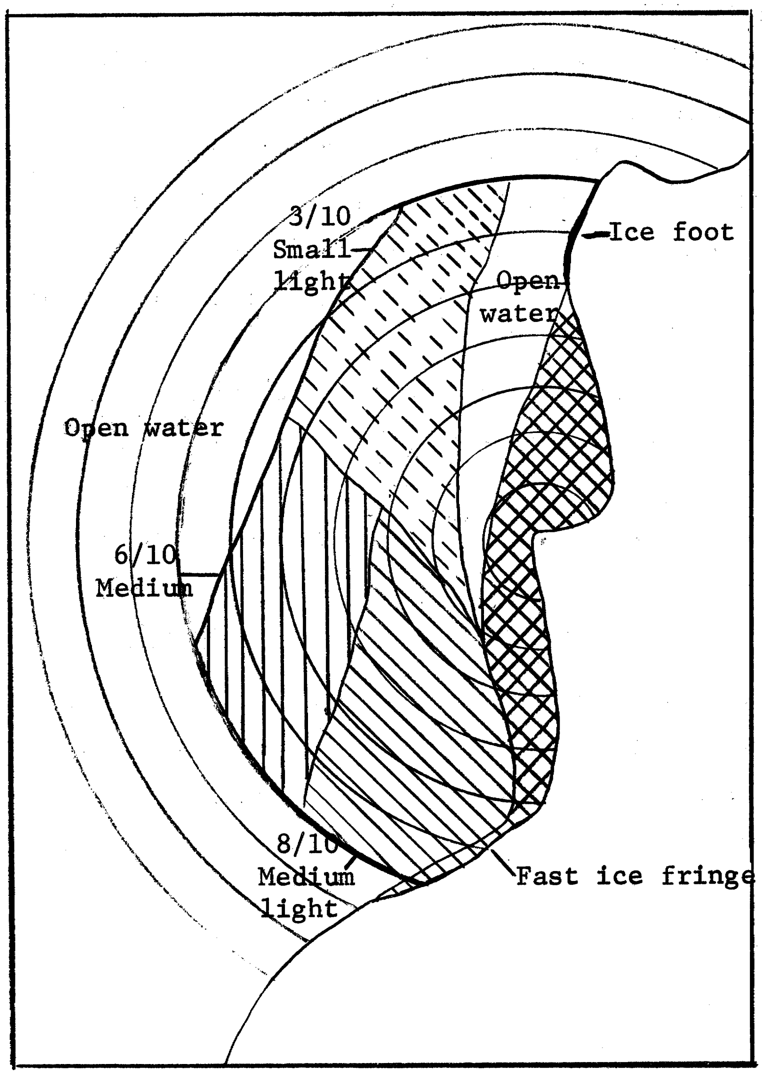
G) Meteorological data: Wind direction should be given in points of the compass and wind speed according to the Beaufort scale.

Short cuts: If there is no change in the distribution of water or ice since the previous observation, write 'NO CHANGE' across the face of the map. If there is open water or fast ice to the horizon, write 'OPEN WATER' or 'FAST ICE TO THE HORIZON.'

If there is any feature of the ice which you feel is important, such as the way it is drifting, or some startling change in the previous 24 hours which is not shown on the map, you are encouraged to write a note on the back of the observation sheet--but this must not replace completion of the map.

3. RETURNING COMPLETED DATA SHEETS

In order to keep track of the ice situation and so that data can be abstracted for use by the U. S. Coast Guard, Lake Survey and Weather Bureau, it is requested that the completed maps of Saturday through Friday be mailed on Friday each week. Franked addressed envelopes are provided for this purpose.



Scale 1:240,000

LAKE MICHIGAN ICE PROJECT, 1964-65

Date January 24, 1964. Time of observation (local) 1200 hrs.

Observation Point Lighthouse. Height of Ob. point 47 ft. a.l.w.d.

Visibility unlimited miles. Wind direction NW.

Wind Speed, Beaufort scale 4.

(Note that distance of horizon from 47 ft. above lake surface is 7 miles.)

A list of useful terms in describing ice and ice distribution.

BRASH ICE	Accumulation of small fragments not more than 2 yards across, the wreckage of other forms of ice.
CLOSE PACK ICE	Composed of floes mostly in contact. Ice cover 5/10 to 8/10.
CONSOLIDATED ICE PACK	Pack ice composed of floes that are frozen together. Ice cover 10/10.
FAST ICE	Ice which remains fast, generally in the position where originally formed, and which may attain considerable thickness. It is found along coasts, where it is attached to the shore, or over shoals.
FRAZIL CRYSTALS	Fine spicules or plates of ice, suspended in water. Usually the first sign of ice.
FROST SMOKE	Fog-like clouds, due to the contact of cold air with relatively warm water, which appear over newly-formed leads and pools or leeward of the ice edge, and which may persist while young ice is forming. (Also known as sea smoke, lake steam.)
ICE BLINK	A typical whitish glare on low clouds above an accumulation of distant ice. It is especially glowing when observed on the horizon. (q.v. water sky.)
ICE COVER	The amount of ice encountered; measured in tenths of the visible water surface covered with ice.
ICE EDGE	The boundary at any given time between open water and floating ice of any kind, whether pack ice or fast ice.
ICE FLOE	A single piece of floating ice, other than fast ice, of any size larger than 10 yards across.
ICE FOOT	Ice attached to the coast and aground, unmoved by tides, seiches or waves and remaining after the fast ice has moved away.
ICE RIND	A thin, elastic, shining crust of ice, after formation on quiet water. Thickness less than 2 inches. It is easily broken by wind or swell, and makes a tinkling noise when passed through by a ship.
OPEN PACK ICE	Floes seldom in contact with many leads and pools. Ice cover 1/10 to 5/10.
PACK ICE	Term used in a wide sense to include any area of floating ice, other than fast ice, no matter what form it takes or how it is disposed. (Also known as drift ice.)

PANCAKE ICE	Pieces of newly-formed ice, usually approximately circular, about 1 foot to 3 yards across, and with raised rims, due to the pieces striking against each other, as the result of wind and swell.
VERY CLOSE PACK ICE	Almost all floes in contact with each other with little water showing. Ice cover 8/10 to 10/10.
WATER SKY	Typical dark patches and strips on low clouds over a water area enclosed in ice or beyond its edge. It is due sometimes to an open water area beyond the horizon. (q.v. ice blink.)
WINTER ICE	More or less unbroken level ice, originating from young ice, and more than 6 inches thick.
YOUNG ICE	Newly-formed level ice generally in the transition stage of development from ice rind, or pancake ice to winter ice; thickness from 2 to 6 inches.

PART II

WINTER TEMPERATURE STRUCTURE OF LAKE MICHIGAN

Vincent E. Noble

INTRODUCTION

A study of the winter temperature structure of the water of the lake is a necessary corollary to the study of the growth of ice on the lake. In order to be able to say that we completely understand the nature of the ice cover formation, we must be able to predict the amount of ice cover in advance. It is immediately apparent that, in order to develop a causative relationship to be used in the prediction of the amount of ice, we must begin with an investigation of the energy budget of the freezing and thawing processes of the lake. Further consideration shows that the integrated result of the heating and cooling processes that act upon the water mass of the lake is exactly indicated by the temperature structure of the water itself.

THE BASIC DATA

Water temperature data have been made available from the U. S. Public Health Service, Great Lakes-Illinois River Basins Project. These data were obtained from temperature recorders installed at 19 locations in the lake. Figure 1 shows the location of the temperature recording stations. Each station had a temperature recorder at 10, 15, 22, 30, and 60 meters, and every subsequent 30-m level down to the bottom. The temperature recorders were a bourdon-tube-driven stylus scribing on waxed chart paper. The temperature span was 0 to 30C on a 70-mm scale. The chart transport was a clock-driven motor that transported the paper in steps every 30 minutes. The time-base of the recording was a transport of 1/6 cm in 30 min. The overall accuracy of carefully calibrated temperature recorders appeared to be about ±0.3C. All of the data were read to the nearest indicated 0.1C, and averaged before appropriate temperature corrections were applied from the calibration marks put on the charts before the meters were set on station and again after they were removed from the water. Mechanical failure occurred at some of the

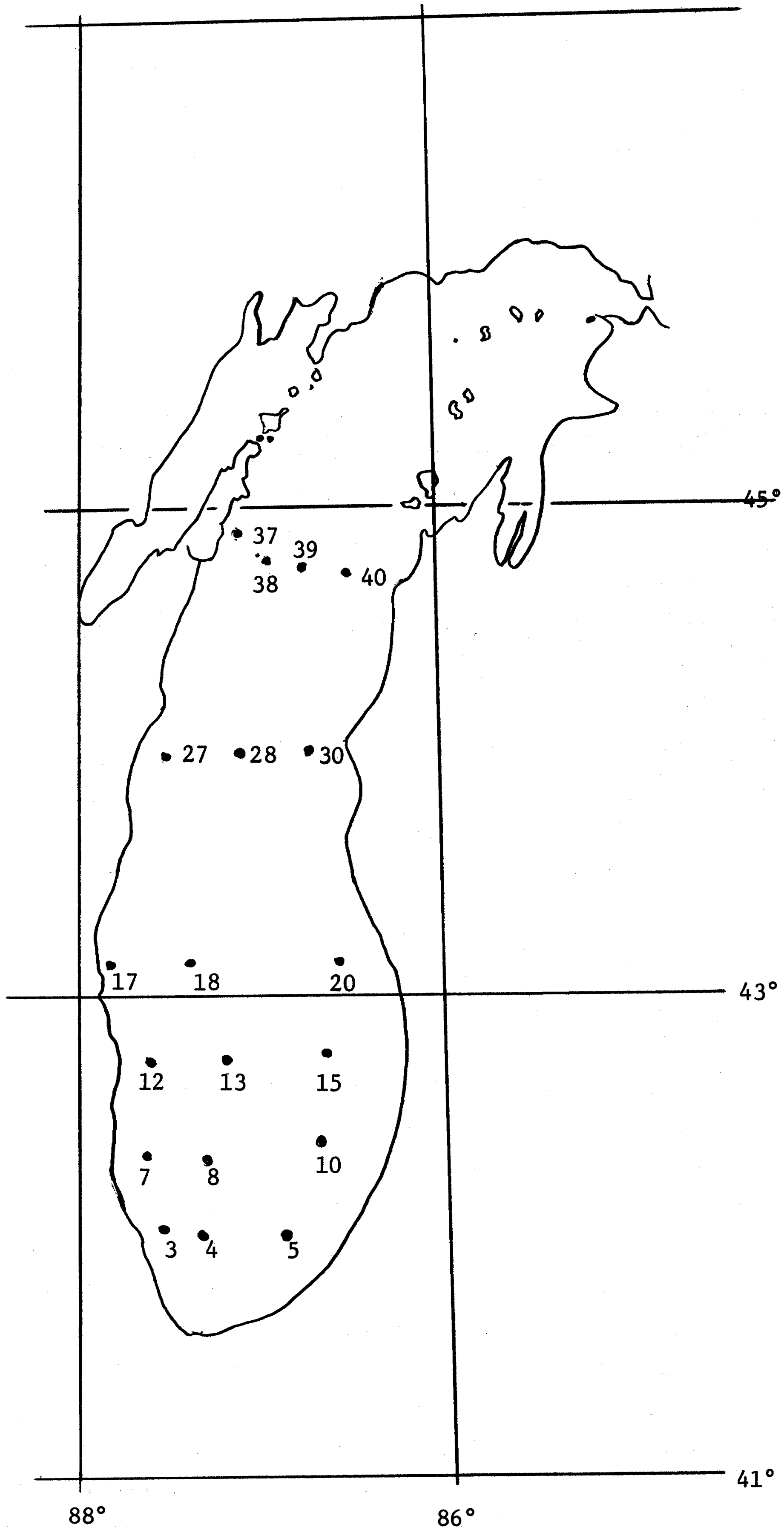


FIGURE 1. U. S. Public Health Service temperature stations.

recording levels, and some of the functioning meters did not have adequate calibration points. In each case, when uncalibrated instruments were used in the analysis of the data, the inclusion of such instruments in indicated. Unless otherwise noted, only calibrated data are used in the analysis.

For the purposes of this program, the temperature records were read as averages for 90-min intervals. The time base of the temperature records was then corrected for individual variations in the speed of the several clock motors, and daily temperature averages were computed. The daily temperatures were averaged for weekly intervals beginning on 1 October, and the indicated calibration corrections were applied to the weekly averages. All of the weekly temperature averages from each of the temperature recorders are presented in Appendix I. Stations 3, 4, 17, 18, 20, and 39 were occupied during the winter of 1962-63. Stations 3, 4, 5, 7, 8, 10, 12, 13, 15, 17, 18, 20, 27, 28, 30, 37, 38, and 40 were occupied during the winter season of 1963-64.

WINTER LAKE MECHANICS

Never before has the entire basin of a large lake been so completely instrumented. This is the first opportunity that we have had to study directly the nature of the cooling process as it occurs within a large body of water that has been thermally stratified during the summer season. Church (1942) was the first to indicate the importance of winter storms in cooling the lake. The daily temperature records from the continuous recordings of each of the instruments were examined in order to study the mixing of the water caused by the early winter storms.

Effect of Early Winter Storms

The operational definition for the determination of wind mixing at any given level was that there should be a fluctuation of the temperature greater that 0.3C within the day. A short-term rise of the temperature at a given level indicated that warmer water had been mixed downward by the influence of the wind.

The most dramatic evidence of wind-driven mixing into the lower layers of the lake is offered by the temperature recording from the 240-m level at station 39 during the 1962-63 season. From 2-14 December 1962, the recorded temperature at the 240-m level was 6.0C with occasional slow drifts to 5.9C or 6.1C. Evidences of wind mixing began to appear on 14 December. Table 1

TABLE 1. Temperature Record, Station 39, 16-19 December 1962.

LAKE Michigan	STATION 39	START 12-2-62 1650 CST
END 7-19-63 1000 CST	DEPTH 240 meters	RECORDING INTERVAL 30 min
LAT. 44°45'N	LONG. 86°45'W	No temperature calibration

	DATE			
TIME ENDING	16 Dec	17 Dec	18 Dec	19 Dec
0130	6.0	6.5	7.0	7.0
0300	6.0	6.8	7.0	6.9
0430	6.0	6.9	7.0	6.8
0600	6.0	6.9	7.0	6.9
0730	6.0	6.9	6.9	6.9
0900	6.0	6.9	6.7	6.7
1030	6.1	6.9	6.8	6.7
1200	6.1	6.9	6.8	6.4
1330	6.1	6.9	6.8	6.1
1500	6.0	6.9	6.8	6.1
1630	6.0	6.9	6.9	6.1
1800	6.1	7.0	6.9	6.1
1930	6.1	7.0	6.9	6.1
2100	6.1	7.0	6.9	6.1
2230	6.1	7.1	6.8	6.1
2400	6.3	7.1	7.0	6.1

presents the temperatures as read for the period 16 through 19 December. Sufficient mixing occurred to raise the temperature from 6.1C at 2230 on 16 December, to 6.5C at 0130 on 17 December, to 6.9C at 0430 on 17 December.

Table 2 presents a summary of the temperature readings during the periods defined as wind-mixing at the 240-m level of station 39 during the 1962-63 season. During the 10-day period of 15-25 December, the average temperature of the water at this level was raised by 0.4C. The magnitude and speed of the temperature fluctuations at this level indicate that they were a wind-driven phenomenon, and not a result of a gradual heating or cooling of the water of the lake. The net change of the average temperature demonstrates that the observed fluctuations were the result of a true mixing process, and not merely a measurement of an internal wave, seiche, or any similar event.

All of the records from the 1963-64 season were examined for indications of storm mixings. These indications have contributed to a description of the fall overturn and cooling of the water mass of the lake. As the water is cooled from the surface, the summer thermal stratification is reduced, and the depth of the mixed layer increases until wind-driven mixing occurs down to the bottom of the lake basin.

TABLE 2. Wind-Mixing at Station 39, 1962-63.

LAKE Michigan STATION 39 DEPTH 240 meters

LAT. 44°45'N LONG. 86°45'W

	TEMPERATURE, °C				
DATE	AVERAGE	HIGH	LOW	AVERAGE PRECEDING DAY	AVERAGE FOLLOWING DAY
12-15-62	6.1	6.3	6.0	6.1	
12-16-62	6.1	6.3	6.0		
12-17-62	6.9	7.1	6.5		
12-18-62	6.9	7.0	6.8		
12-19-62	6.4	7.0	6.1		6.2
12-22-62	6.2	6.5	6.0	6.2	
12-23-62	6.3	6.6	6.1		
12-24-62	6.5	6.7	6.3		
12-25-62	6.5	6.7	6.4		6.5

Table 3 presents the date of occurrence of the first wind mixing observed at 30 m and greater depths. The upper recorders (10, 15 and 22 m) were generally above the thermocline and would be expected to show evidences of mixing throughout the year. It is uncertain whether the first mixing date for the 30-m level is the first actual mixing of the fall season because of the lake starting date of the temperature records. Appendix II presents the depths and stations at which mixing was observed for each of the days that were interpreted as storms from the temperature records. The depth of mixing generally increases with the onset of winter.

TABLE 3. Date of Occurrence of First Observed Wind-Mixing, 1963-64.

DEPTH	DATE	STATION	DEPTH	DATE	STATION
30 m	23 Nov	4, 13, 18	120 m	3 Dec	38
60 m	30 Nov	8, 18	150 m	9 Dec	38
90 m	3 Dec	38	180 m	1 Jan	40

Comparison of the first mixing statistics with the weekly average temperature data (Appendix I) shows some broad features that describe the mixing process. When the upper levels of the lake have cooled to approximately 10C, mixing occurs at a depth of 30 m. As the lake further cools to 7-8C, the water is further mixed to 60 m. Cooling another degree permits mixing at 90 m, and by the time the lake has reached 4-5C the water is mixed down to the bottom.

A synopsis of the weather conditions obtained from the daily weather maps for each of the days with significant mixing is presented in Appendix III. These data show that the winds occurring on the days of deep mixing are not extraordinary, being generally of the order of 15-20 mph. It is therefore shown that, for average winds and the neutrally stable condition existing within the isothermal lake, the wind stress is sufficient to cause major vertical circulation of the water mass.

Cooling of the Lake

The weekly average temperatures were examined for each of the station lines crossing the lake. The three station temperature profiles on each of the station lines provide enough data to form a hypothesis regarding the mechanism for cooling the water of the lake in the fall of the year. The instruments were removed from the water in early spring, so that the spring warming was not fully observed from these data. There is tentative verification of the model to be described below, and appropriate means for testing the hypothesis will be presented. This model is based on the weekly average temperature structure of the water mass, and depends upon a prevailing westerly wind.

The data from stations 3, 7, 12, 17, 27, and 37 indicate that the cooling process begins at the edges of the lake. If there were no motion of the water mass, this edge cooling would be anticipated from the consideration of a simple heat transfer problem involving a thin-edged slab (the water of the lake). The motion of the water and the warming of the cold air by heat transfer from the lake are perturbations on the simple slab problem.

Figure 2 shows the weekly average temperatures for the 10-m level at stations 3, 4, 18, 20, and 40 for the winter season of 1963-64. The water depths at stations 3 and 4 are 16 and 50 m, respectively. Stations 18 and 20 are 100 m, and station 40 is 200 m. The graph shows that the early winter temperatures are reasonably close for all of the stations and that the initial cooling rates are approximately equal. However, there is much larger total temperature change in the shallow stations than appears in the deeper stations, in spite of the fact that the shallow stations are in the southern (warmer) end of the lake. Also, the spring warming of the shallow stations appears much earlier and proceeds at a more rapid rate for the shallow stations than for the deep stations.

The study of the storm-mixing of the water at each of the stations shows

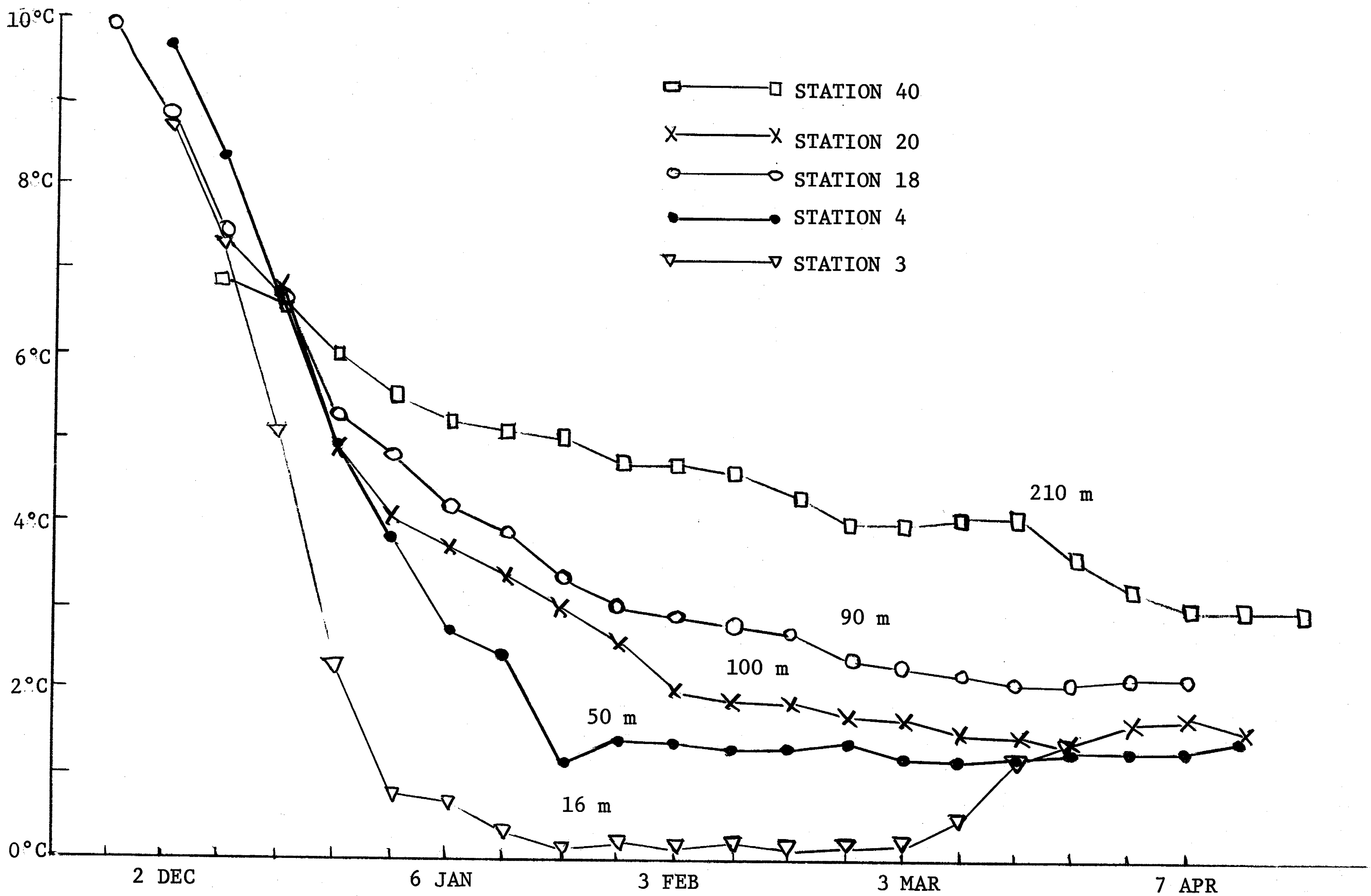


FIGURE 2. Weekly average temperature, 10-meter depth, 1963-64.

that the water column is mixed down to the bottom of the basin during the fall of the year. This corresponds with the usual concept of the "fall overturn" of the lake. The weekly average temperature data, however, present evidence for an additional, large scale, motion of the water mass in the lake basin. A cross-section of the weekly average temperature profile along one of the station lines is shown in Appendix IV. The shallow station at the western shore shows the rapid response of the "edge effect," the deep station west of the mid-line of the basin is nearly isothermal, and the deep station east of the mid-line shows a slightly warmer mass of water below 30 m and cooler water above the bottom. Unfortunately, there were no shallow-water stations operating on the eastern edge of the lake. Only the southern station line is shown in Appendix IV, but the general features appeared on all six lines.

Based on the effect of early winter storms, and on the temperature patterns exhibited by the several station lines, the following model for the mechanism of the fall cooling of the lake is proposed.

At the end of the summer, the lake is thermally stratified with a well-developed thermocline. As the air temperature falls with the onset of fall and winter, cold westerly winds begin to blow over the lake. The cold air meets the warm water on the west side of the lake, cooling the water and warming the wind. The air is warmed continuously as it crosses the lake. It is therefore expected that the western edge of the lake will begin to cool first. As the surface water of the lake falls in temperature, the density effect of thermal stratification is reduced, and the wind-mixing can drive deeper into the water mass of the lake. When the upper mixed layer reaches a temperature of the order of 6 to 7C, the wind stress caused by a fall storm is sufficiently great to drive the warmer surface water down into levels of 4C. The wind-driven mixing of the lake becomes increasingly deeper as the surface of the water is cooled. While the air is cooling the lake, it is removing heat from the surface water and is being warmed. It is therefore expected that the gross cooling of the lake should begin in the west and progress from west to east. The wind-driven mixing of the lake will be present over the entire lake basin, so that by the end of the cooling period only a slight west-to-east temperature gradient will be expected.

The wind-driven setup of the lake during the summer is well documented. (e.g. Bellaire 1963). During the fall of the year, similiar wind stresses will be exerted upon the surface of the water, but the effect of the thermal stratification will be first reduced and ultimately nearly eliminated as the

lake approaches isothermal conditions. Sinking and upwelling accompany the summer setup. It is therefore expected that a similar pattern of sinking and upwelling will exist throughout the winter, and that the isothermal nature of the lake will enable a vertical circulation pattern to be established and maintained rather easily.

It is therefore proposed that a substantial vertical circulation pattern is a permanent feature of the lake during the late fall and winter periods when the water surface is free from ice. It is further suggested that the gyre is not strictly vertical, but that the water sinking from the surface is inclined to the south under the influence of the Coriolis force. A schematic representation of a vertical section of the lake is shown in Figure 3, illustrating the envisioned nature of the vertical gyre and the effect of the wind-driven mixing. Figures 4 and 5 show temperature profiles along two of the station lines, illustrating the temperature characteristics which indicate the existence of the vertical gyre.

The vertical circulation pattern would explain the warmer water mass in the upper mid-depth of the eastern portion of the lake, the cooler water in lower mid-depth in the same area, and the more nearly isothermal characteristic of the western portion of the lake. It is anticipated that there will be a secondary edge effect at the eastern shoreline that would give rise to more rapid local cooling and heating, as are observed at station 3 and the other shoreline stations at the west shore of the lake.

A similar vertical circulation should persist through the spring of the year, until temperature stratification begins to appear again. The vertical circulation will probably be reduced as a consequence of the inversion that is formed by the warm spring winds over the cold water as described by Bellaire (1965).

The existence of the spring vertical circulation should be revealed by the distribution of the phytoplankton bloom in the lake. During the fall and winter seasons, the water is thoroughly mixed, and the distribution of nutrients and oxygen should be uniform throughout the lake. In the spring, the edges of the lake begin to warm more rapidly than the center, and the phytoplankton production should begin to increase as a result of the increase in water temperature and the amount of available light for photosynthesis. Since the phytoplankton have a slight sinking tendency, the existence of an upwelling would tend to maintain a higher percentage of plankton near the surface, and to be reflected in an increase in the magnitude of the spring bloom. Therefore

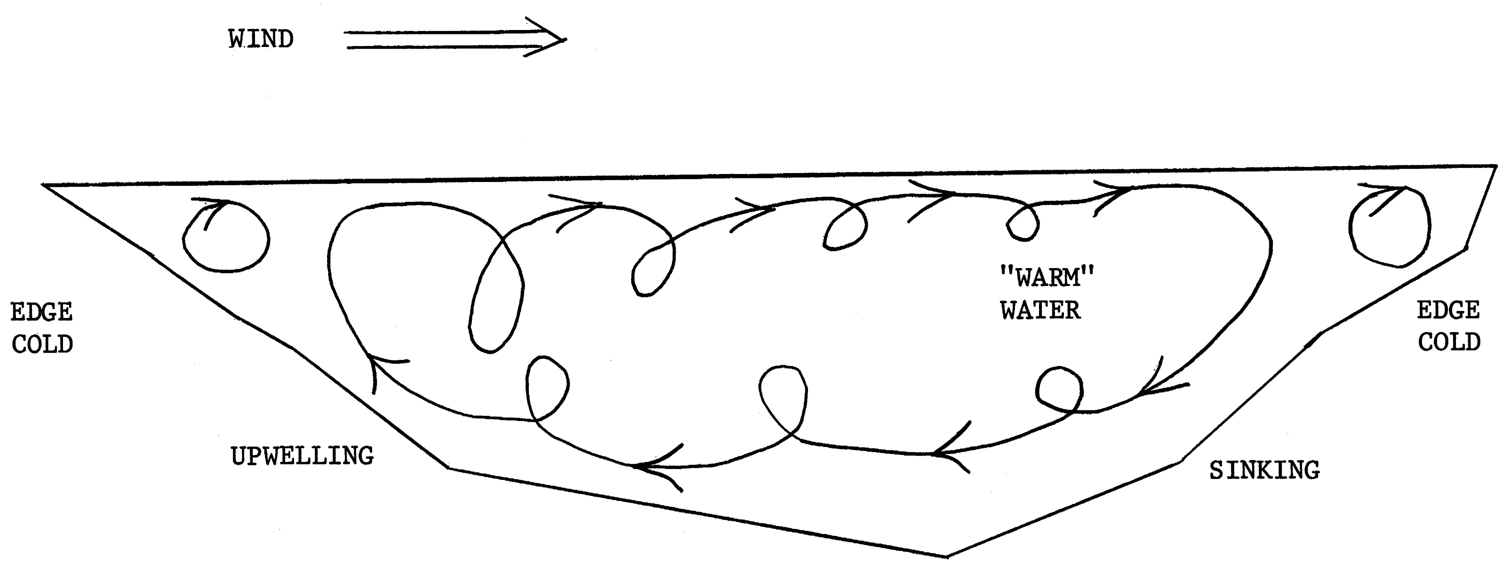
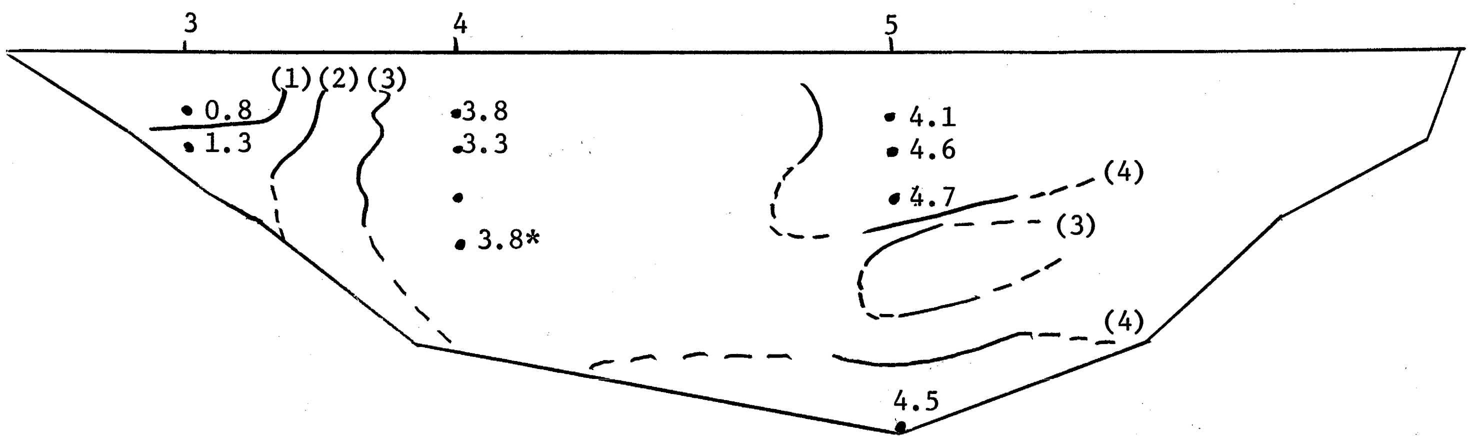


FIGURE 3. Schematic of winter circulation pattern (vertical gyre).



*Instrument not calibrated

FIGURE 4. Weekly average temperatures, stations 3, 4, 5, week ending 30 December 1963.

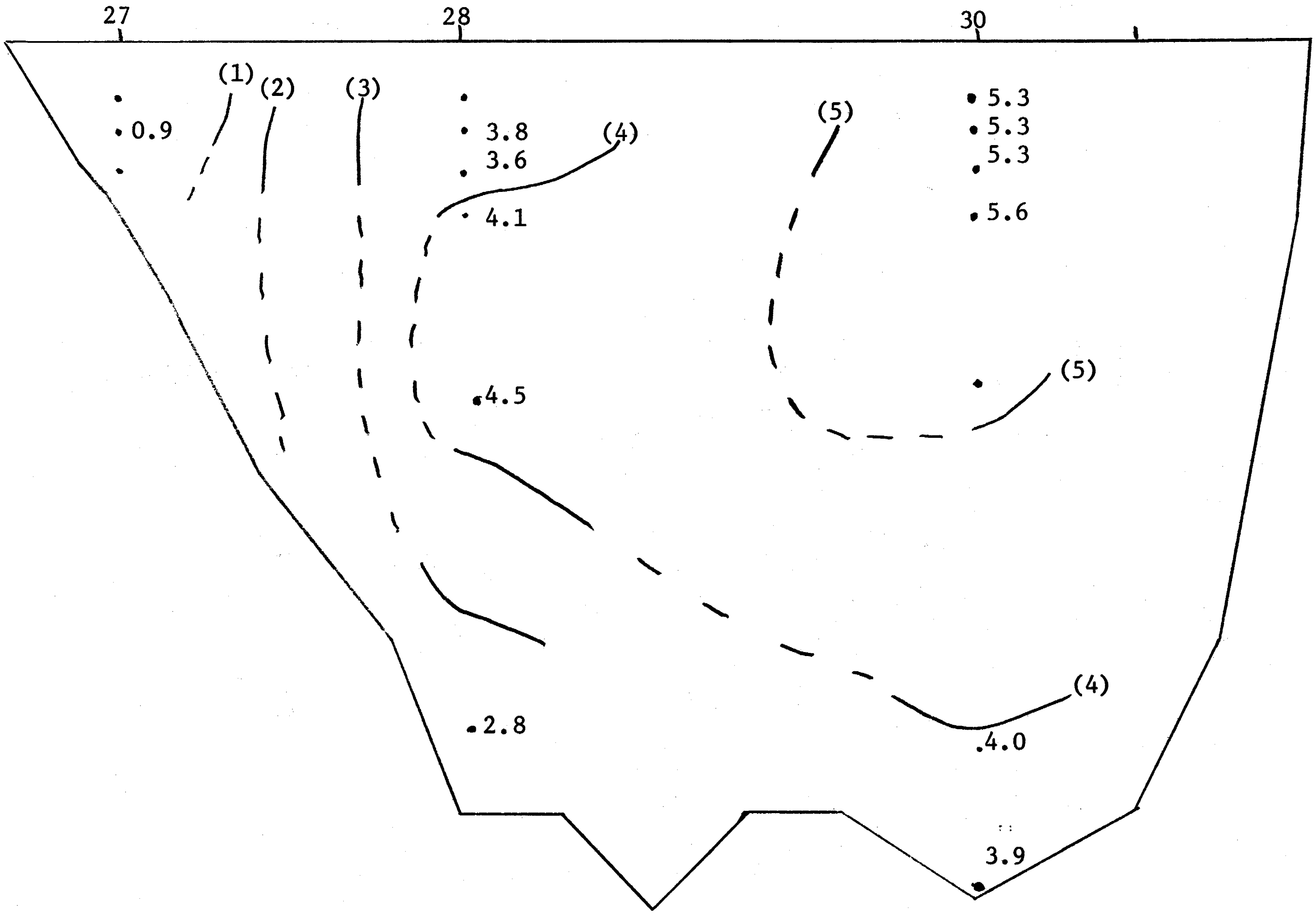


FIGURE 5. Weekly average temperatures, stations 27, 28, 30, week ending 30 December 1963.

the plankton bloom should be observed at the western edge of the lake before it appears at the eastern side, and should extend farther off shore from the western side than it does from the eastern side of the lake. In areas of extremely high fertility, the effects of the postulated gyre may be measurable only during the very early stages of the bloom.

PREDICTIVE STUDIES

Heat Losses of the Lake

An accurate means of estimating the heat budget of the lake will be necessary for the ultimate successful prediction of the amount of ice cover to be expected during any given period. The difficulties inherent in estimating a heat budget for the lake are indicated in the above discussion of the temperature structure and winter circulation pattern of the lake. There is not yet enough known about the detail of the thermal structure of the lake to estimate a heat budget with accuracy desired in a final ice-prediction method. It is possible, however, to use selected representative temperature profiles as an index of the relative heat budget from year to year, and thereby to establish an initial empirical index for the beginning prediction of ice.

The temperature recording stations were occupied during two extremely different winter seasons. These seasons represent extremes in the amount of ice cover that exists on the Great Lakes. A comparison between the temperature profiles obtained from stations occupied for both seasons has revealed the possibility of adopting a prediction index for the amount of ice cover to be expected in a given winter. The temperature profiles from stations occupied during both seasons are presented in Figures 6 and 7. The temperature profiles for the cold season of 1962-63 are illustrated by solid dots and solid lines. The profiles for the warm season of 1963-64 are shown by open circles and broken lines. The temperature profiles for stations 3, 4, 17, 18, and 20 are shown for the two seasons in Figure 6. Station 39 was not occupied during the 1963-64 season, so the 1962-63 profile is compared with the average of stations 38 and 40 for 1963-64 in Figure 7.

Stations 3, 4, and 17 were rejected as potential ice predictors because of the "edge effect" described above. Figure 7 shows that the average between stations 38 and 40 during the 1963-64 season does not form the basis for an accurate comparison with the 1962-63 data from station 39.

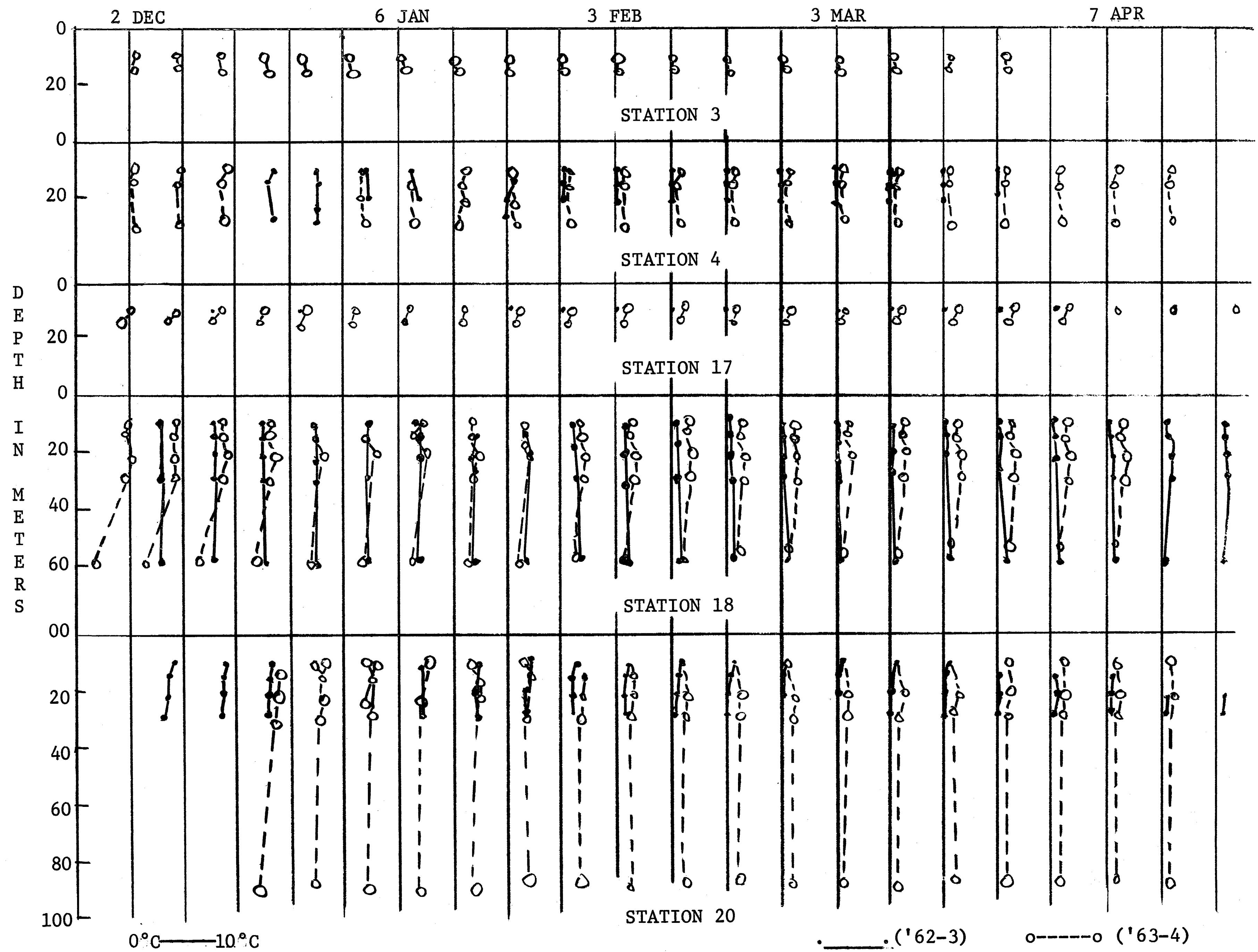


FIGURE 6. Weekly average temperature.

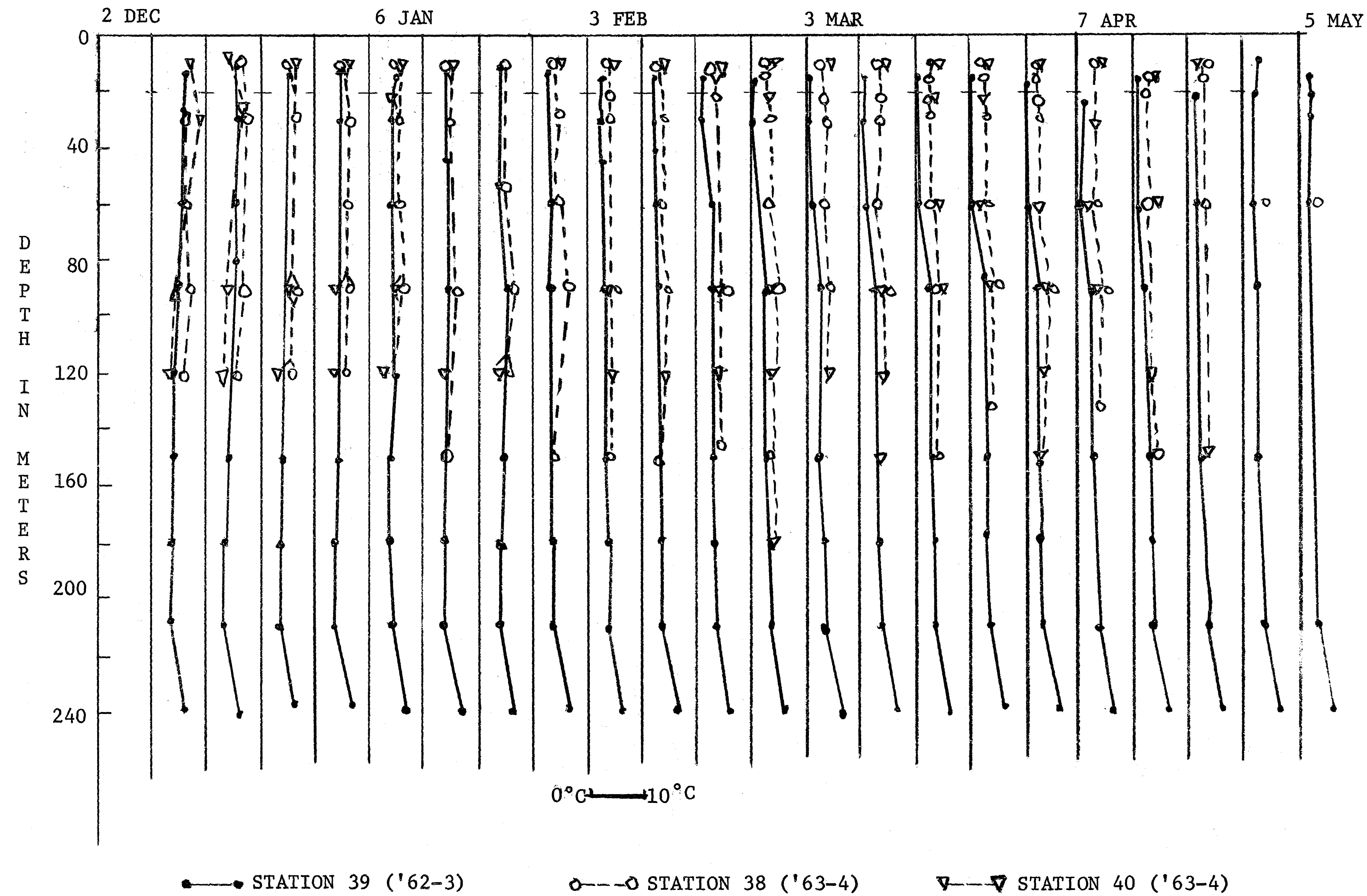


FIGURE 7. Weekly average temperature.

The recorded temperature for the 10-m level at station 20 was approximately the same for both years. The deep levels of station 20 were not usable for both seasons, but the 15-, 22- and 30-m levels showed characteristics similar to those shown at all levels by station 18. According to the above model for the winter circulation of the lake, station 18 should be more representative of the true heat budget of the lake, as a consequence of both the wind mixing and of the upwelling expected from the vertical circulation pattern.

Figure 8 shows the differences in temperature at station 18 between the 1963-64 and the 1962-63 seasons. The difference in weekly average temperature is plotted for each depth and is graphed as a function of the week of the winter season. The temperature measurements began on the week ending 2 December. The temperatures at the 10-, 15-, 22-, and 30-m levels were 2-3C warmer in 1963 than in 1962. Due to variations in the cooling rates, this difference was reduced during the freezing, or ice-forming period, but the same relative difference was restored by about 17 February. The 60-m temperature was about 2C colder in 1963 than in 1962 on 2 December, but was approximately the same for both years after 3 February. These data therefore indicate that the amount of heat lost from the upper 30 to 50 meters of the lake is a constant, that is, independent of the severity of the winter.

An independent confirmation of the hypothesis that the same amount of heat was lost from the lake in each of the two years is offered by a comparison of the air temperatures recorded at Muskegon and Milwaukee. The air temperatures were compared by considering the cumulative centigrade degree-days on both sides of the lake. The use of centigrade degree-days gives a direct measure of freezing and thawing exposure. When the centigrade degree-days increase positively, the total number is an indicator of the thawing exposure. When the number of degree-days is negative, or the cumulative number of degree-days begins to decrease, the number is an indicator of freezing exposure.

Figure 9 gives the cumulative number of centigrade degree-days measured at Muskegon and Milwaukee during both the 1962-63 and the 1963-64 seasons. The differences between the exposures at Muskegon and Milwaukee are a measure of the heating of the atmosphere by the lake. The number of degree-days at both stations increased positively from 1 October until 2 December, at which time the cumulative total begins to decrease with the onset of freezing weather. The total continued to decrease through 10 March in the 1962-63

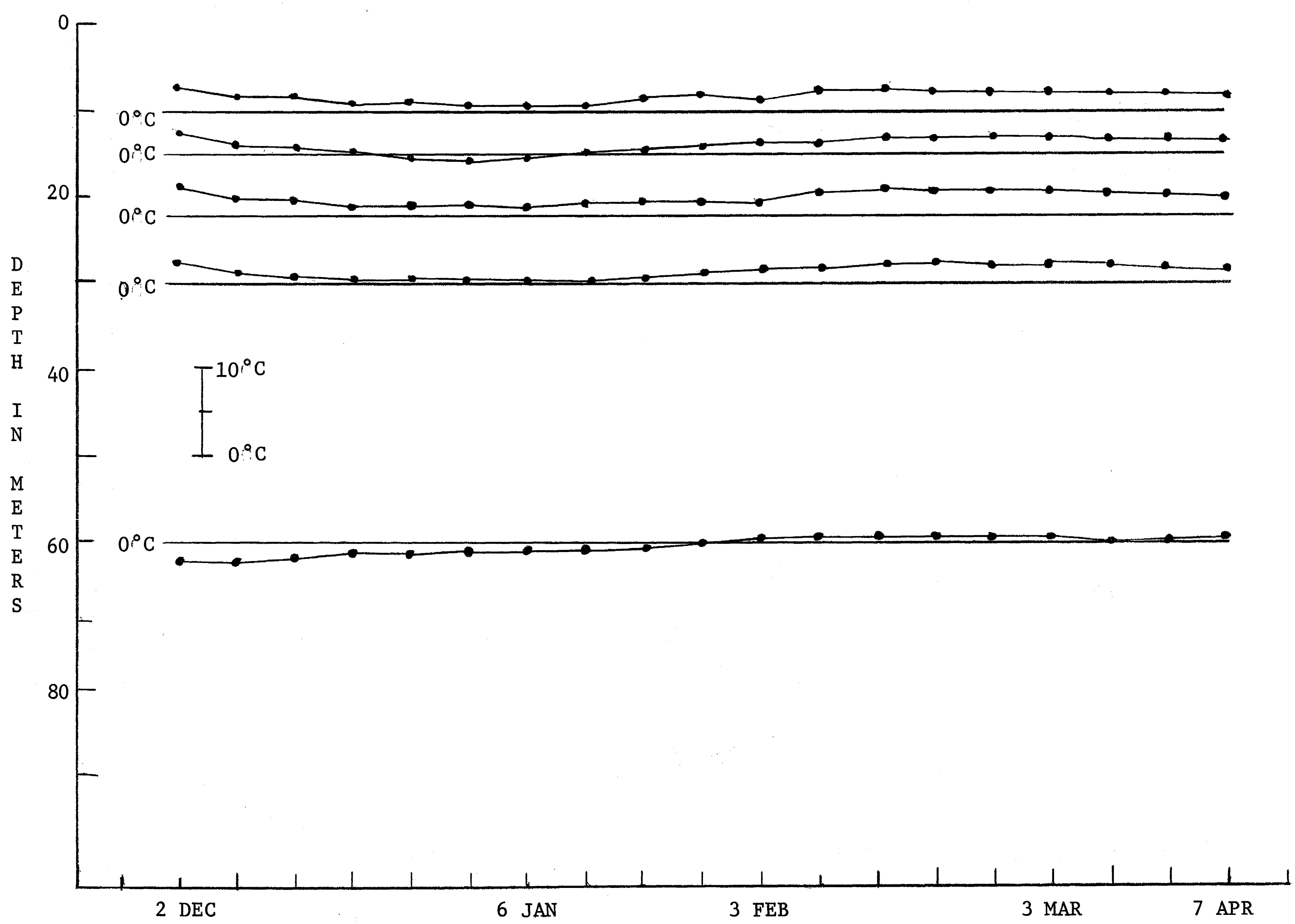


FIGURE 8. Weekly average temperature difference, station 18. (T_A '63-4) - (T_A '62-3).

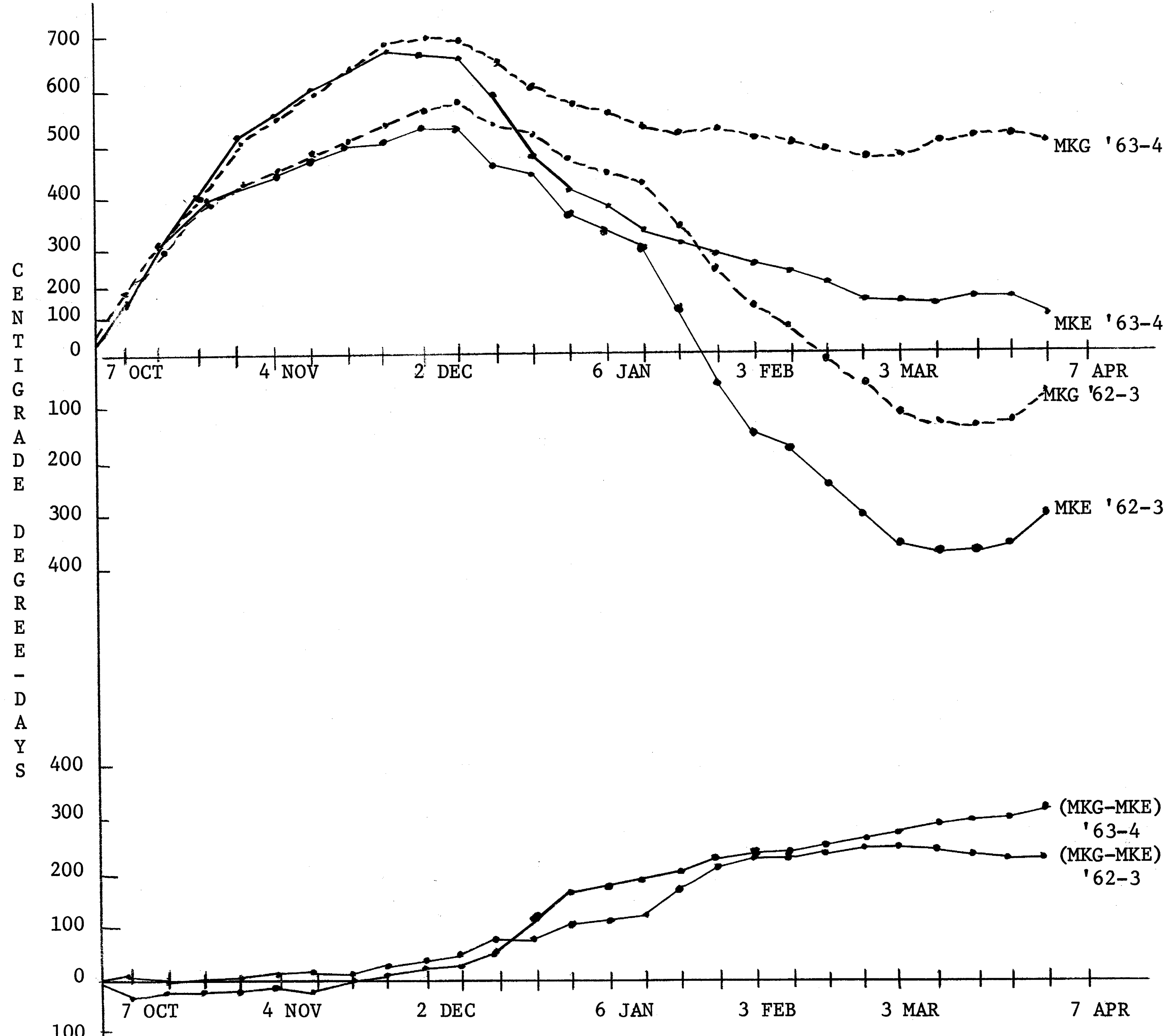


FIGURE 9. Cumulative degree-days (centigrade). Air temperature, Milwaukee and Muskegon.

season, but levelled off around 10 February during 1963-64. The decrease in degree-days was of the order to 800 at Milwaukee during the 1962-63 season, but only of the order to 500 during 1963-64. These figures are an indication of the relative severities of the two seasons.

The amount of atmospheric heating by the lake is demonstrated by the increase in air temperature of the prevailing wind as it moves across the lake from Milwaukee to Muskegon. The differences between the cumulative number of degree-days at Muskegon and Milwaukee for the two seasons are shown in Figure 9. It is significant that the amount of atmospheric warming was nearly identical during the two seasons. This confirms the observation that the heat loss from the lake was nearly identical for the two seasons, and appears to be independent of the air temperature.

A Potential Method for Prediction of Ice Cover

The information included in this report serves to emphasize the basic insufficiency of data regarding either the ice cover of Lake Michigan, or the winter temperature structure of the lake. From the limited data available, it is only possible to indicate a potential, qualitative method for the prediction of the ice cover for any given season.

The data have demonstrated a heat loss from the upper 50 meters of the lake that is independent of the air temperature of the winter season. It should therefore be possible to predict the amount of ice to be expected in any given winter from the fall temperature structure of the lake.

Analysis of the cooling process for the lake shows that shore temperatures are neither representative of the heat content of the total water mass, nor would they be useful for the prediction of a winter's ice cover. Measurement of near-shore water temperatures would be useful only for gauging the short-term rate of change of local ice.

The temperature profiles shown for station 18 in Figure 6 show rather large temperature differences at the 60-m level for the two years that the recorders were in operation. The temperature record from the 1962-63 season (solid line) shows that the water at the 60-m depth cooled significantly during the cold winter. Comparison of the temperature from 1962-63 for the week ending 21 April with the temperature at the same depth for the week ending 25 November of the 1963-64 season (broken line), shows that there was little temperature change at the 60-m level of station 18 during the summer of 1963. It is therefore indicated that the instantaneous temperature profile

of the water mass is the result of an integration of the heating and cooling processes experienced by the lake for a period at least as great as one year. This evidence substantiates the belief that the winter ice cover may be predicted from the fall temperature of the lake.

In recent work on the comparison of the change in the average temperature of the lake with the long-term climatological trend, Ayers (1965) has developed a technique for predicting the temperature trend of the lake on a five-year basis. The parameters used in the prediction scheme are air temperature, cloudiness, and storm passages. Richards (1964) has published statistics relating the short-term formation of ice to local freezing exposure.

A program for the prediction of the ice cover to be expected on Lake Michigan would be based upon the application of the above mentioned relationships. Ayers' relationship would be used to maintain a running prediction of the anticipated water temperature for the lake for five years ahead. These predictions would indicate general trends toward warming or cooling within the long-term range of the the forecasts. The temperature of the water at selected deep-water stations would be monitored during the late summer and early fall to obtain an estimate of the total amount of ice cover to be expected during the following winter. The fall estimate for any given winter would be necessary because of the wide variation to be found within long-range trends in nature. During the late fall and early winter, local climatological data would be monitored at selected stations around the lake to provide a basis for short-term forecasts of freeze-up dates. The fall water temperature, local weather history, and five-day to two-week weather forecasts would be used to predict icing condition within a two-week period. During the winter, ice type, cover, and thickness would be documented on a weekly basis. In the spring, the ice data, local weather history, and five-day to two-week weather forecasts would be used to predict the break-up date.

Need for Further Information

The techniques proposed above are based on rough empirical relationships between the several factors bearing on the formation of an ice cover on the lake. As described in the first section of this report, there is no documentation of the amount of ice actually existing on the lake for any sequence of years. Specific documentation is necessary for a period of at least five years in order to adequately test the above hypotheses, and to develop

quantitative predictions. The data needed are: amount and distribution of ice cover; ice type and thickness; air temperature and winds; amount of sunlight and clouds; water temperature structure of the lake; infrared absorption and reflectance for the water, snow cover, and different types of ice.

RECOMMENDATION FOR CONTINUING PROGRAM

Conversations with various governmental agencies interested in the ice problem, with private organizations wanting accurate ice forecasts, and with scientists interested in studying the mechanics of the process of ice formation have led to the following recommendation for a program of continuing work on lake ice. This program is designed for the most efficient use of presently available capabilities, and represents the most economical way of continuing to collect the necessary data.

The primary source for the gross description of the total ice cover on the lake would be from satellite imagery and high-altitude aircraft (U-2) photographs. The U. S. Weather Bureau, through the Applications Branch of the National Weather Satellite Center, has been working on ice reconnaissance since project TIREC in the spring of 1962. These results have not been continuous, but form the basis for a more concentrated effort, now that the methods have been worked out. Some high-altitude aircraft photos have been made available to the U. S. Lake Survey to demonstrate their applicability. Lack of sufficient photo-interpretation information has limited the usefulness of these data. Continuous use of these two methods would provide the necessary gross description of ice cover and its changes throughout the winter season.

Low-level photo flights have been carried out by the Coast Guard in cooperation with the Lake Survey. These flights provide detailed coverage of local areas and can supply some information for the description of ice type. The additional experience necessary for accurate photo-identification of ice type will depend on increased surface surveillance of ice type and thickness, to be correlated with aircraft flights.

Both the Lake Survey and the Coast Guard have summer personnel who might be trained and used for identification of ice type and field measurement of ice thickness around the lake during the winter season. Presently, the Coast Guard has been receiving location maps distribution by the Weather Bureau, and has been describing the extent and type of ice cover in the

immediate vicinity of the Coast Guard stations on a dialy basis. This program might be expanded slightly and supplemented with thickness information.

A minimum of five continuous years of data on the duration and areal extent of the ice cover, with regard to both type and thickness, will be necessary to provide estimates of the possibility of extending the shipping season on the Great Lakes. Additional detailed information about the present durations of the shipping seasons will be necessary before it will be possible to make accurate estimates of the costs and benefits to be accrued from programs directed toward keeping ports open.

The problem of keeping ports open is somewhat distinct from the hazards of navigation in the open lake after the vessel leaves dock. The insurance underwriters will need more data to establish rates for the extended season.

Air temperature, wind, and cloud cover data are now available around the Great Lakes, but it is suggested that at least some of the weather stations should be equipped with instruments to record the amount of incident radiation from the sun and sky. The radiation should be measured as total incident energy in both the visible and infrared portions of the spectrum.

Temperature profiles would be obtained from a few recording buoy stations, and surface temperatures would be measured with infrared thermometers carried along on the photo flights. Continuous subsurface temperature recorders are preferable to BT's because they permit averaging temperatures over significant periods of time. The temperature recordings should be supplemented with BT data from the Coast Guard ice-breakers while on duty. Measurement of the lake surface temperature with an infrared detector has become a familiar technique, e.g. Ragotzkie and Bratnick (1965).

The infrared absorption and reflectance, and the thermal conductivities for water, snow cover, and the different types of ice may be estimated at present, and are the present object of several research programs based on arctic research and the application of satellites to problems in the earth sciences.

The program described above will provide all of the data necessary for a complete and accurate computation of the total heat and energy budget of the lake, as indicated by Scott and Ragotzkie (1961) and Scott (1964). The necessary program is very broad in scope, and must be continued for a sufficient period of time to insure adequate statistics for the many-variable problem.

This program will require only slight additional operations from each of the several agencies presently concerned with the ice problem on the Great Lakes. It has been suggested that the Weather Bureau is both the logical and proper agency to perform the function of the collection of the data and the distribution of the results. The Lake Survey is the proper agency to maintain archives of the yearly data pertinent to the ice problem.

It might be proper for the initial phases of the program, the tests of the prediction method, and the design of the experiemnts to be directed by competent research personnel within a university, and for the heat budget and statistical evaluations to be done by them while searching for improved relationships to be used for better ice prediction.

ACKNOWLEDGMENTS

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Particular appreciation is extended to P. Bhatia and L. Featheringham for their herculean efforts in reducing the innumerable miles of analog temperature records.

The authors are indebted to the U. S. Weather Bureau, U. S. Lake Survey, U. S. Coast Guard, and the U. S. Public Health Service for their co-operation and consultation while this program was being carried out.

The advice and consultation of Dr. J. C. Ayers throughout the program is greatfully appreciated.

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APPENDIX I

WEEKLY AVERAGE TEMPERATURE DATA

Temperature Recording Stations

STATION	LATITUDE	LONGITUDE	DEPTH
3	42°02.5'N	87°32'W	16 m
4	42°01'N	87°20'W	50 m
5	41°59'N	87°00'W	65 m
7	42°25'N	87°45'W	23 m
8	42°23'N	87°25'W	100 m
10	42°23'N	86°38'W	70 m
12	42°46'N	87°42'W	22 m
13	42°45'N	87°22'W	120 m
15	42°44'N	86°35'W	95 m
17	43°08'N	87°51'W	30 m
18	43°08'N	87°24.5'W	90 m
20	43°08'N	86°35'W	100 m
27	44°03'N	87°33'W	45 m
28	44°04.5'N	87°14.5'W	150 m
30	44°04'N	86°48'W	160 m
37	44°50'N	87°09'W	25 m
38	44°47.5'N	86°57.5'W	120 m
39	44°45'N	86°45'W	250 m
40	44°43'N	86°31'W	210 m

WEEKLY AVERAGE TEMPERATURE, 1962-63

Depth	Week Ending																									
	December					January				February				March					April				May			
	2	9	16	23	30	6	13	20	27	3	10	17	24	3	10	17	24	31	7	14	21	28	5	12	19	26
Station 3																										
15 m				2.9	1.7	1.4	1.3	0.3	0.4	0.4	0.2	0.2	0.2	0.1	0.3	0.6										
Station 4																										
10 m				5.1	4.2	2.5	2.1	0.9	0.4	0.2	0.2	0.0	0.1	0.1	0.2	0.2	0.5									
15 m				4.9	4.2	2.8	2.1	0.9	0.4	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.4									
22 m				4.9	4.4	3.3	2.3	1.2	0.3	0.2	0.1	0.1	0.1	0.0	0.2	0.2										
Station 17																										
10 m		5.5	2.4	2.2	2.2	2.3	2.2	0.8	0.1	0.1	0.1	0.0	0.0	0.0	0.2	0.2	0.2	0.9	1.5	1.9	3.0					
Station 18																										
10 m	5.9	6.0	4.9	4.5	3.9	3.4	3.3	2.7	1.6	1.0	0.6	0.2	0.1	0.1	0.0	0.0	0.1	0.2	0.4	0.6	1.0					
15 m	6.3	6.2	5.4	5.0	4.5	4.0	3.8	2.9	2.2	1.5	1.1	0.9	0.4	0.2	0.2	0.1	0.2	0.4	0.5	0.9	1.2					
22 m	6.2	6.2	5.4	5.0	4.7	4.0	3.6	2.8	2.1	1.4	1.1	0.7	0.2	0.1	0.2	0.2	0.3	0.6	0.8	1.3	1.4					
30 m	6.5	6.4	5.6	5.1	4.6	4.1	4.0	3.4	2.8	1.9	1.3	1.1	0.6	0.1	0.2	0.2	0.2	0.5	0.9	1.3	1.5					
60 m	5.5	5.5	5.3	5.0	4.8	4.0	3.9	3.5	2.8	2.0	1.5	1.1	1.1	0.9	0.7	0.6	1.0	1.0	0.8	0.4	0.7					
Station 20																										
10 m	8.7	8.5	7.1	6.5	5.7	5.2	5.1	4.2	2.6	2.0	1.6	1.4	1.2	1.0	1.0	1.1										
15 m	7.7	7.7	6.2	5.7	5.1	4.6	4.4	3.5	2.2	1.4	1.1	0.9	0.5	0.6	0.4	0.4	0.5	0.6	1.0							
22 m	7.6	7.9	6.4	5.9	5.2	4.6	4.4	3.5	1.9	1.5	0.8	0.7	0.4	0.3	0.2	0.2	0.3	0.5	0.9	1.2	1.5					
30 m	6.8	7.5	6.0	5.6	5.1	4.4	4.3	3.5	1.9	1.7	0.7	0.6	0.3	0.2	0.1	0.1	0.1	0.2	0.8	1.1	1.2					
Station 39																										
15 m		6.0	5.6	5.3	4.8	4.5	4.4	4.0	3.1	2.4	2.3	1.1	0.7	0.6	0.6	0.6	0.5	0.8	1.1	1.2	1.4	1.8	2.0	2.3	2.5	2.8
30 m		5.8	5.5	5.2	4.7	4.3	4.2	3.8	3.0	2.4	2.2	1.0	0.2	0.2	0.1	0.1	0.2	0.4	0.9	1.1	1.4	1.9	2.2	2.3		
60 m		5.7	5.4	5.1	4.7	4.2	4.1	3.8	3.2	2.6	2.2	1.7	1.6	1.1	0.7	0.4	0.3	0.4	0.7	0.9	1.2	1.6	1.8			
90 m*		4.9	5.5	5.2	4.9	4.4	4.2	3.9	3.4	2.9	2.8	2.7	2.6	2.6	2.6	2.6	2.6	2.3	2.0	1.9	2.0	2.1				
180 m*		3.4	3.2	3.3	3.6	3.3	3.3	3.3	3.1	3.0	3.0	3.0	2.9	2.9	2.9	2.9	2.9	2.9	3.0	3.0	3.0	3.0	3.0			
210 m*		3.1	3.1	3.3	3.2	3.3	3.4	3.2	3.0	2.9	2.9	2.9	2.9	3.0	3.0	3.0	3.0	2.8	3.0	3.0	3.0	3.0				
240 m*		6.0	6.1	6.4	6.5	6.4	6.1	5.8	5.7	5.8	5.8	5.7	5.8	5.8	5.7	5.7	5.7	5.8	5.8	5.8	5.8	5.8	5.8			

*No calibration

WEEKLY AVERAGE TEMPERATURE, 1963-64

Depth	Nov. 25	Dec. 2	Dec. 9	Dec. 16	Dec. 23	Dec. 30	Jan. 6	Jan. 13	Jan. 20	Jan. 27	Feb. 3	Feb. 10	Feb. 17	Feb. 24	Mar. 3	Mar. 10	Mar. 17	Mar. 24	Mar. 31	Apr. 7	Apr. 14	Apr. 21	Apr. 28	May 5
Station 3																								
10 m	10.5	8.8	7.3	5.1	2.3	0.8	0.7	0.3	0.1	0.2	0.1	0.2	0.1	0.1	0.2	0.5	1.2	1.4						
15 m	10.9	9.4	7.8	5.7	3.2	1.3	1.1	0.6	0.2	0.3	0.3	0.4	0.3	0.2	0.1	0.8	1.3	1.5						
Station 4																								
10 m	11.1	9.7	8.4	6.7	4.9	3.8	2.7	2.4	1.1	1.4	1.4	1.3	1.3	1.4	1.2	1.2	1.2	1.3	1.3	1.3	1.4			
15 m	10.7	9.3	7.9	6.2	4.7	3.3	2.6	2.3	1.0	1.3	1.2	1.1	1.2	1.2	1.0	1.1	1.0	1.1	1.2	1.2	1.3			
30 m*	10.8	9.6	8.2	6.9	5.0	3.8	3.0	1.3	1.4	1.7	1.5	1.6	1.4	1.3	1.4	1.1	1.2	1.2	1.6	1.3	1.5			
Station 5																								
10 m		9.4	8.1	6.8	5.1	4.1	3.6	3.4	2.2	2.3	2.4	2.3	2.2	1.9	1.7	1.9	1.5	1.5	1.5	1.5	1.7			
15 m		9.3	8.4	7.1	5.2	4.6	4.1	3.8	2.4	2.5	2.6	2.7	2.7	2.5	2.3	2.2	2.0	2.0	2.0	2.1	2.2			
22 m		9.5	8.2	7.0	5.4	4.7	4.4	4.1	2.7	2.7	2.8	2.7	2.7	2.6	2.5	2.6	2.2	2.4	2.3	2.3	2.5			
30 m		8.3	6.9	5.8	3.9	3.0	2.8	2.4	1.1	1.1	1.1	1.2	1.1	1.1	1.0	1.0	0.6	0.8	0.7	0.9	1.0			
60 m		4.5	4.8	5.5	5.7	4.5	3.8	3.6	3.5	2.6	2.3	2.3	2.4	2.5	2.1	1.7	1.8	1.7	2.0	2.0	2.3			
Station 7																								
10 m	9.5	8.1	6.4	4.6	1.2	0.8	0.8	1.0	0.6	0.5	0.2	0.3	0.3	0.7	0.4	0.9	1.4	1.9	1.7					
15 m	9.5	8.3	6.4	4.7	1.3	1.1	1.0	1.0	0.9	0.5	0.2	0.3	0.3	0.5	0.5	1.0	1.5	1.7	1.8					
Station 8																								
10 m*		8.6	7.7	6.1	5.0	4.6	4.0	3.8	3.1	3.0	2.6	2.4	2.6	2.4	2.2	2.2	2.2	2.3						
22 m		8.3	7.2	5.6	4.3	3.8	2.9	2.8	2.6	2.3	1.7	1.7	1.8	1.7	1.5	1.4	1.2	1.5	1.5	1.4				
30 m*		8.5	7.7	6.2	5.0	4.7	4.0	3.6	3.0	3.0	2.4	2.2	2.2	2.1	2.0	2.0	2.0	2.1	2.1					
60 m		5.0	6.4	5.9	5.3	5.0	4.3	4.1	3.9	3.6	3.0	3.0	3.0	2.9	2.7	2.5	2.4	2.6	2.7					
90 m		4.0	4.0	4.1	4.6	4.1	3.7	3.4	2.9	2.9	2.7	2.8	2.7	2.4	2.1	2.0	2.0	2.0	2.1	2.1				
*Station 10***																								
10 m		8.9	7.3	5.7	4.8	3.8	3.1	2.9	2.3	2.4	2.3	2.1	1.9	1.6	1.9	2.1	2.0	1.8	1.9					
15 m		9.3	8.2	6.4	5.9	4.7	3.8	3.5	2.9	2.8	2.4	2.1	1.8	1.6	1.5	1.7								
22 m		9.5	8.2	6.5	5.4	4.6	4.0	3.7	3.1	3.1	2.7	2.7	2.6	2.1	2.4	2.5	2.3	2.2	1.9					
30 m		9.0	7.5	5.9	4.9	3.8	3.0	2.9	2.2	2.2	2.0	2.0	1.9	1.4	1.9	2.1								
Station 12																								
10 m	9.1	7.7	6.4	4.2	1.9	0.6	1.0	0.5	0.2	0.2	0.0	0.5	0.6	0.8	0.2	0.8	1.4							

*No calibration
**All records short

Depth	Week Ending: Nov. 25	December 2	December 9	December 16	December 23	December 30	January 6	January 13	January 20	January 27	February 3	February 10	February 17	February 24	March 3	March 10	March 17	March 24	March 31	April 7	April 14	April 21	April 28	May 5
Station 13																								
10 m	8.5	7.2	6.5	5.4	3.8	3.5	3.3	3.1	2.8	2.6	2.3	2.1	2.0	1.8	1.6	1.2	1.1	1.4	1.4					
15 m	9.6	8.3	7.7	6.3	4.9	4.4	4.3	4.1	3.5	3.2	2.9	2.7	2.5	2.3	2.1	2.0	2.1	2.1	2.1	2.1				
30 m	9.0	8.4	7.8	6.7	5.4	5.1	5.0	4.8	4.7	3.6	3.4	3.3	3.1	2.9	2.4	2.1	2.2	2.2	2.1	2.1				
90 m	3.9	4.0	4.0	4.1	4.4	4.4	4.2	4.0	3.6	3.3	3.0	2.9	2.9	2.7	2.3	2.3	2.5	2.8	2.5	2.5				
*Station 15***																								
10 m*		10.3	9.6	7.6	5.9	5.7	5.1	4.7	3.9	3.9	3.5													
22 m*		9.0	8.4	6.5	4.8	4.5	3.8	3.2																
30 m		9.6	9.0	7.1	5.3	5.2	4.5	4.1	3.0	3.0	3.0													
Station 17																								
10 m*	10.2	8.8	7.0	5.4	3.2	2.5	2.0	2.4	2.1	2.0	2.2	2.3	2.2	2.2	2.0	2.2	2.5	2.6	2.7					
15 m*	8.5	7.4	5.7	4.5	2.2	1.7	1.3	1.7	1.1	1.3	1.4	1.6	1.1	1.0	0.8	1.2	1.5	1.6	1.6					
Station 18																								
10 m	9.9	8.8	7.4	6.7	5.3	4.8	4.2	3.9	3.3	3.0	2.9	2.8	2.7	2.4	2.3	2.2	2.1	2.1	2.2	2.2				
15 m	9.6	8.5	7.2	6.0	5.0	4.3	3.1	3.4	2.9	2.8	2.6	2.5	2.4	2.2	2.0	2.1	2.1	2.0	2.1	1.9				
22 m	10.6	8.5	8.2	7.1	5.9	5.6	5.1	4.6	4.1	4.0	3.8	3.5	3.3	3.1	2.9	2.9	2.9	2.9	2.9	2.9				
30 m	9.5	8.7	7.5	6.4	5.4	4.9	4.4	4.0	3.6	3.4	3.0	2.9	2.8	2.8	2.6	2.5	2.6	2.5	2.5	2.5				
60 m	3.4	3.4	3.2	3.6	4.0	3.7	3.0	2.9	2.4	2.1	2.0	1.8	1.7	1.6	1.4	1.3	1.1	1.0	1.0	1.1				
Station 20																								
10 m				6.8	4.9	4.1	3.7	3.4	3.0	2.6	2.0	1.9	1.9	1.7	1.7	1.5	1.5	1.4	1.7	1.7	1.5			
15 m* **				8.0	6.2	5.4	4.8	4.6	4.1	3.7	3.0													
22 m				7.6	5.7	4.9	4.5	4.1	3.7	3.2	2.6	2.7	2.8	2.4	2.4	2.2	2.1	2.0	2.2	2.1	2.2			
30 m				7.4	5.6	4.8	4.2	3.9	3.2	2.8	2.4	2.3	2.3	2.1	2.0	1.8	1.8	1.7	1.9	1.8	1.8			
90 m				3.9	4.0	4.3	3.9	3.6	3.1	2.5	2.3	2.1	2.0	1.8	1.6	1.4	1.4	1.4	1.4	1.4	1.5			
Station 27																								
15 m			4.7	3.2	1.1	0.9	1.3	1.4	1.1	1.1	0.6	0.4	0.4	0.5	0.4	0.8	1.0	1.0	1.0	0.8	1.0	1.7		
Station 28																								
15 m			5.7	5.1	4.1	3.8	3.2	3.0	2.7	2.8	2.7	2.4												
22 m			5.5	4.8	3.8	3.6	3.3	3.1	2.7	2.7	2.7	2.5	2.5	2.3	2.1	2.0	2.0	2.1	2.0	2.1	2.2			
30 m			5.6	5.1	4.5	4.1	4.0	3.8	3.0	3.0	3.0	3.0	2.8	2.8	2.7	2.5	2.3	2.3	2.2	2.2				
60 m			5.8	5.6	4.9	4.5	4.1	3.9	3.5	3.5	3.2	2.9	2.8	2.7	2.7	2.5	2.4	2.3	2.1	2.2	2.3	2.5		
120 m			2.6	2.7	2.8	2.8	3.0	3.1	2.9	3.0	3.1	2.9	2.6	2.5	2.5	2.6	2.4	2.6	2.7	2.4	2.5	2.6		

*No calibration
**All records short

Depth	Nov. 25	Dec. 2	Dec. 9	Dec. 16	Dec. 23	Dec. 30	Jan. 6	Jan. 13	Jan. 20	Jan. 27	Feb. 3	Feb. 10	Feb. 17	Feb. 24	Mar. 3	Mar. 10	Mar. 17	Mar. 24	Mar. 31	Apr. 7	Apr. 14	Apr. 21	Apr. 28	May 5
										Week Ending														
Station 30																								
10 m			6.3	5.7	4.8	5.3	3.7	3.5	3.2	3.2	3.0	3.1	2.5	2.7	2.5	2.3	1.9	2.0	1.9	1.8	2.1	2.4		
15 m			6.6	6.0	5.2	5.3	5.1	4.0	3.6	3.4	3.1	3.1	2.9	2.9	2.6	2.4	2.4	2.4	2.2	1.9	1.7	2.0		
22 m			6.4	5.7	4.9	5.3	3.9	3.5	3.4	3.3	3.2	3.2	2.7	2.8	2.9	2.6	2.4	2.4	2.5	2.4	2.6	2.8		
30 m			5.8	6.0	5.4	5.6	4.5	4.2	4.2	4.0	3.9	3.7	3.5	3.6	3.6	3.5	3.4	3.3	3.2	3.2	3.4	3.9		
120 m			3.1	3.1	3.7	4.0	3.8	3.5	3.1	3.0	2.8	2.8	2.6	2.4	2.4	2.0	1.8	1.6	1.6	1.5	1.5	1.6		
150 m			3.5	3.6	3.8	3.9	3.7	3.5	3.3	3.2	3.0	3.0	2.8	2.7	2.6	2.5	2.6	2.3	2.2	2.2	2.1	2.4		
Station 37																								
10 m			5.4	5.5	4.7	3.8	2.7	2.7	2.2	2.2	2.0	1.7	1.6	1.5	1.2	1.4	1.2	1.1	0.6	0.7	0.9	1.5		
15 m			5.1	5.4	4.4	3.4	2.8	2.6	2.3	2.3	2.2	2.1	2.0	2.0	1.7	1.9	1.8	1.6	1.5	1.6	2.2	2.6		
22 m			5.2	5.2	5.5	4.9	4.2	3.4	3.1	2.7	2.8	2.4	2.2	2.2	2.1	2.0	1.9	1.9	1.8	1.7	1.3	1.5		
30 m			4.4	4.9	3.7	2.9	2.2	1.9	1.8	1.8	1.4	1.2	1.0	1.0	0.8	1.0	0.8	0.7	0.3	0.2	0.6	1.1		
60 m			4.5	4.8	3.9	3.4	2.7	2.4	2.3	2.1	2.0	2.1	2.2	1.8	2.0	1.5	1.4	1.3	1.1	1.2	1.3			
Station 38																								
10 m			6.6	5.8	5.2	4.7	4.3	4.2	4.0	3.4	3.0	2.6	2.8	2.6	2.3	2.2	2.2	2.3	2.3	2.4	2.3	2.4	2.4	
15 m			6.4	5.8	5.1	4.7	4.3	4.0	4.0	3.3	2.9	2.5	2.8	2.5	2.2	2.0	2.0	2.1	2.1	2.2	2.3	2.3	2.4	
22 m			6.5	6.0	5.5	4.9	4.2	4.1	4.1	4.0	3.7	3.1	2.8	2.4	2.6	2.6	2.4	2.0	2.2	2.1	2.2	2.2	2.3	2.3
30 m			6.6	6.2	5.9	5.6	5.3	5.0	4.5	4.2	4.0	4.0	3.7	3.7	3.5	3.5	3.4	2.9	2.7	2.6	2.2	1.9	2.0	2.0
60 m			6.4	5.9	5.5	5.0	4.9	4.3	4.3	3.7	3.5	3.1	3.2	3.1	3.0	2.7	3.0	2.9	3.1	3.0	3.1	3.1	3.2	3.3
90 m**			7.0	7.0	6.6	6.0	6.3	6.7	6.5	6.1	5.8	5.6	5.6	5.3	5.3	5.0	5.3	5.2	5.2	5.1				
120 m**			5.2	5.1	5.5	5.7	5.4																	
150 m			3.8	3.6	3.9	4.1	4.0	4.0	3.9	3.5	3.1	3.1	3.0	3.0	3.0	2.4	2.9	2.8	2.6	2.4	2.3	2.2	2.2	2.6
Station 40																								
10 m			6.9	6.6	6.0	5.5	5.2	5.1	5.0	4.7	4.7	4.6	4.3	4.0	4.0	4.1	4.1	3.6	3.2	3.0	3.0	3.0		
22 m			6.2	5.7	5.3	4.9	4.6	4.4	4.1	4.0	3.7	3.5	3.2	3.1	3.1	3.0	2.9	2.8	2.7	2.4	2.4	2.3		
30 m			8.5	7.4	6.5	6.2	5.6	5.4	4.7	4.4	4.2	3.9	3.3	3.2	3.1	2.8	2.9	2.4	2.3	2.4	2.6	2.8		
60 m			5.5	5.9	5.1	5.1	4.5	4.3	3.5	3.3	3.1	3.0	2.8	2.6	2.7	2.5	2.5	2.1	2.0	2.1	2.2	2.4		
90 m			4.5	4.3	5.2	5.1	4.9	4.6	4.6	3.8	3.7	3.5	3.4	3.2	3.1	2.9	3.0	2.7	2.9	2.7	2.5	2.5		
120 m*			3.2	3.3	3.4	3.7	3.8	3.9	3.9	3.9	4.1	3.9	3.9	3.9	3.9	3.5	3.1	3.1	3.0	3.0	3.0	3.0		
150 m*			3.9	4.0	4.2	4.2	4.4	4.3	3.9	3.7	3.5	3.4	3.2	3.2	3.1	2.9	3.0	2.9	2.8	2.6	2.5	2.8		
180 m			3.1	3.1	3.2	3.4	3.4	3.5	3.4	3.8	3.8	3.8	3.9	3.8	3.4	3.1	3.1	3.1	3.0	3.0	3.0	2.9		

*No calibration
**All records short

APPENDIX II

DATES OF ALL WIND MIXING

Criteria for determination of days of wind mixing:

Depth	High-low difference on a single day
30 or 60 meters	0.4°C or more
90, 120, 150 or 180 meters	0.3°C or more

Depths less than 30 m not considered.

1963

DATE	DEPTH	STATIONS
Nov. 23	30 m	4, 13, 18
24-27	30	18
29	30	4, 8, 15
30	30	5, 18
	60	8, 18
Dec. 1	30	18
	60	18
2	30	5, 18
	60	8, 18
3	30	10, 18
	60	18
	90	38
	120	38
4	30	4, 10, 37
	60	5, 8, 40
	90	38
	120	38
5	30	4
	60	5, 8, 28, 30, 38, 40
	90	38, 40
6	30	10
	60	5, 8, 18, 30, 38, 40
	90	38, 40
7	30	10, 40
	60	8, 18, 30, 38, 40
	90	38, 40
8	30	8, 10, 15, 40
	60	28, 30, 38, 40
	90	38, 40
9	30	5, 8, 10, 20, 38, 40
	60	5, 8, 18, 28, 30, 38, 40
Dec. 9	90 m	20, 38, 40
	120	38
	150	38
10	30	4, 10, 15, 37, 40
	60	5, 8, 18, 28, 30, 37, 40
	90	38, 40
	120	38, 40
	150	38
11	30	10, 13, 18
	60	5, 8, 18, 30, 37, 40
	90	38, 40
	120	28
12	30	4, 8, 10, 13
	60	8, 18, 37, 40
	90	20, 40
13	30	15, 18, 40
	60	5, 8, 18, 30, 40
	90	20, 38, 40
14	30	4, 15, 18, 20, 40
	60	5, 18
	90	20, 38, 40
15	30	5, 10, 18
	60	5, 37
	90	13, 20, 38, 40
	120	40
	150	40
16	30	20
	60	5, 18, 30
	90	8, 13, 20, 38, 40
	120	40
17	30	37
	60	5, 40
	90	13, 38, 40

DATE	DEPTH	STATIONS
Dec. 17	120 m	38
	150	40
18	30	4, 18, 28, 37
	60	18, 37
	90	13, 38, 40
	120	38
19	30	4, 5
	60	5, 8, 37
	90	8, 13, 40
	120	38
20	30	37
	60	18, 30, 37
	90	40
	120	40
	150	38
21	30	18
	60	37
	90	20, 38, 40
	120	--
	150	38
22	30	5, 10, 40
	60	37, 40
	90	40
	120	38
23	30	4
	60	30, 37
	90	40
	120	38, 40
	150	38, 40
24	30	--
	60	37
	90	40
	120	30, 38, 40
	150	30, 38
25	30	40
	60	30, 40
	90	--
	120	--
	150	30
26	30	37
	60	30, 37, 40
	90	--
	120	--
	150	38
27	30	--
	60	28, 37, 40
	90	40
	120	--
	150	38
28	30	4
	60	30
	90	13, 40
Dec. 29	30 m	--
	60	30, 40
	90	40
30	30	8
	60	37
	90	--
	120	--
	150	40
31	30	--
	60	(8)
	1964	
Jan. 1	30	4, 15, 37, 40
	60	37
	90	40
	120	40
	150	40
	180	40
2	30	--
	60	30
3	30	4
	60	--
	90	40
4	30	4
	60	30, 40
	90	38, 40
	120	--
	150	30
5	30	--
	60	--
	90	40
	120	--
	150	30, 49
6	30	38
	60	38, 40
	90	38
	120	--
	150	38
7	30	--
	60	--
	90	40
	120	--
	150	40
	180	40
8	30	40
	60	18, 38, 40
	90	40
	120	--
	150	40
9	30	38

DATE	DEPTH	STATIONS
Jan. 10	30 m	--
	60	--
	90	40
11	30	8
	60	--
	90	--
	120	--
	150	40
12	30	28, 37
	60	37
13	30	--
	60	30
	90	--
	120	--
	150	40
14	30	5, 10, 15, 18, 27, 28
	60	5, 28, 37
	90	20
	120	--
	150	--
	180	40
15	30	18
	60	5, 28, 37
16	30	40
	60	40
	90	40
	120	28, 40
17	30	--
	60	28, 37
18	30	(13)
	60	--
	90	(13)
19	30	10
	60	--
	90	40
20	30	--
	60	--
	90	40
	120	--
	150	38
23	30	38
	60	38
	90	38
	120	--
	150	38
25	30	4, 13, 18
	60	8, 38
27	30	4, 20
	60	8
	90	8

DATE	DEPTH	STATIONS
Jan. 31	30 m	8, 38
Feb. 1	30	4, 20
	60	18
2	30	--
	60	--
	90	40
4	30	20
6-7	30	40
	60	--
	90	38
	120	--
	150	38
8	30	--
	60	--
	90	38, 40
	120	--
	150	38
11	30	20
12	30	--
	60	--
	90	8
	120	--
	150	38
14	30	10
	60	37
16	30	10
	60	30, 37, 40
19	30	10
	60	37
	90	40
	120	--
	150	38
22	30	10
	60	37
	90	40
23	30	10
	60	40
	90	40
24	30	--
	60	--
	90	--
	120	--
	150	38
25	30	4
26	30	40
	60	--
	90	--
	120	--
	150	40

DATE	DEPTH	STATIONS
March 3-4	30 m	--
	60	37
	90	38
	120	--
	150	38
5	30	--
	60	30, 40
	90	--
	120	30
	150	30
7	30	--
	60	30
	90	--
	120	--
	150	40
9	30	40
	60	--
	90	38, 40
	120	--
	150	38
10	30	--
	60	38, 40
	90	38, 40
	120	--
	150	38
11	30	5, 38
	60	40
	90	38
	120	--
	150	38
14	30	--
	60	37, 38
15	30	--
	60	30
	90	38
16	30	--
6	60	38
	90	38
17	30	4
	60	--
	90	38
	120	--
	150	30
20	30	--
	60	30, 37, 40
	90	40
21	30	--
	60	--
	90	--
	120	--
	150	38
March 24	30 m	13, 18
	60	37
26	30	13
	60	--
	90	13
	120	--
	150	38
27	30	37
	60	37
29	30	--
	60	37, 40
	90	40
April 1	30	--
	60	37
2	30	--
	60	37
	90	--
	120	--
	150	40
3	30	--
	60	--
	90	--
	120	--
	150	40
5	30	--
	60	37
	90	--
	120	--
	150	40
10	30	--
	60	37
	90	--
	120	--
	150	40
13	30	--
	60	--
	90	--
	120	--
	150	38
29	30	--
	60	--
	90	--
	120	--
	150	38

APPENDIX III

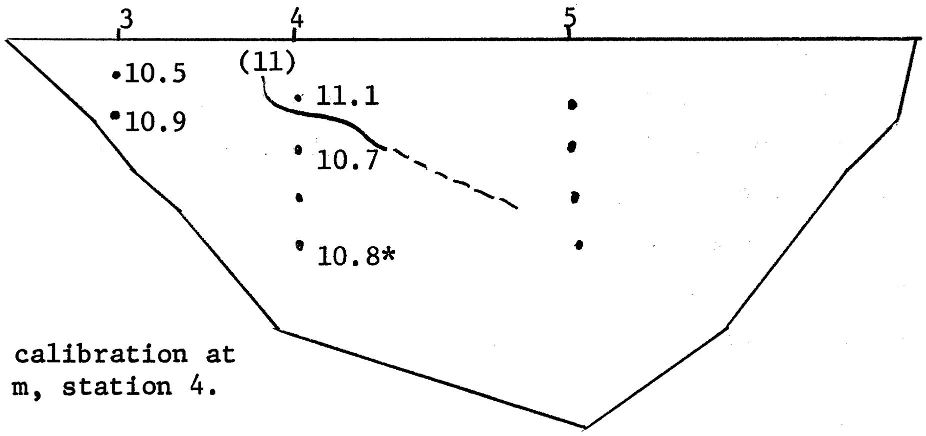
WIND SHIFT DATA FOR LAKE MICHIGAN

Nov. 23	Low pressure. Winds 21-31 mph blowing from west on Chicago, Milwaukee, Grand Rapids, and Traverse City.
27	Cold front moving from north. Northwest winds 9-14 mph.
29	Stormy winds from west hit the upper Michigan. Winds along lake 15-25 mph.
Dec. 2	Low pressure in Ohio and Indiana. Winds 9-14 mph from northeast.
10	Chicago, Milwaukee west winds 9-20 mph. Grand Rapids and Traverse City north winds 9-20 mph.
13	Precipitation on the whole lake. Cold front moving from west.
14	Low pressure. Westerly winds 9-14 mph hitting the lake.
18-19	Low pressure on lower Michigan. Intermittant snow flakes. Winds 9-20 mph from west.
20-21	9-20 mph winds from northwest.
24	Westerly winds 9-25 mph.
25	Cold front moving from north.
26	Warm front moving from south.
27	Precipitation occurring. Low pressure.
Jan. 2	9-20 mph westerly winds.
4	9-25 mph colder winds from northwest.
6	Occluded front.
10	Westerly winds 9-25 mph. Low pressure along the north.
12	21-31 mph winds from northeast.
13	21-37 mph winds from southeast along the southern point of the lake.
14	3-14 mph winds from west.
16	Cold front moving from north.
17	9-21 mph winds from east.
18	Cold front moving from west. 15-20 mph west winds.
20	Precipitation occurring.
23	Cold front from west.
24	Precipitation occurring.
25	21-31 mph winds from southwest. Stormy winds.
Feb. 1	Cold front moving from north.
6	Stormy winds from west 9-14 mph.
13	Low pressure. Precipitation. 9-14 mph westerly winds.

Feb.	25	West wind 21-25 mph. Low pressure.
Mar.	4	Southwest winds 21-25 mph.
	5	32-37 mph winds from northeast. Stormy winds coming from southwest.
	7	Cold front moving in. Low pressure. 32-37 mph winds from west.
	9	Precipitation. 21-25 mph winds from west.
	10	21-25 mph winds from east.
	12	Cold front moving in.
	21	15-20 mph from east.

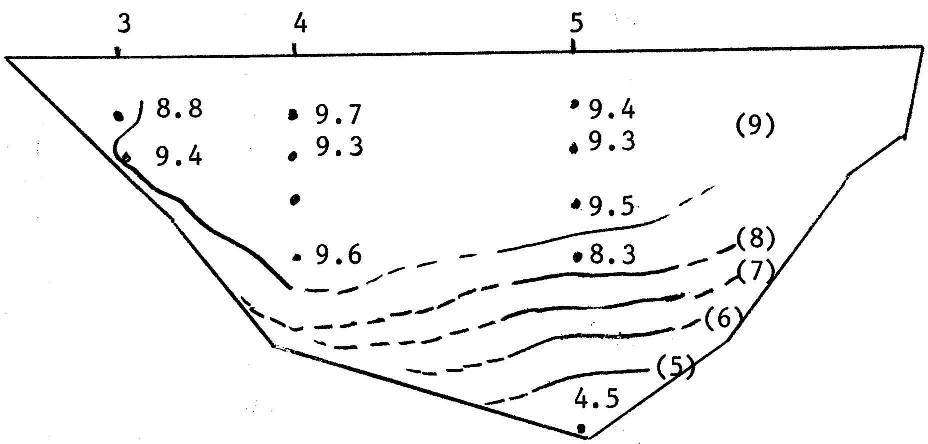
	Fastest Wind Speed	Direction	Date
Chicago O'Hare	38 mph	S	Nov. 22
	21	WSW	Dec. 13
	39	60°	Jan. 12
	35	220°	Feb. 29
	54	10°	March 4
	37	230°	April 13
Milwaukee	36	W	Nov. 23
	28	SW	Dec. 13
	36	NW	Jan. 25
	36	SW	Feb. 29
	47	N	March 5
	51	SW	April 13-14
Green Bay	29	N	Nov. 30
	28	N	Dec. 26
	36	SW	Jan. 25
	34	SW	Feb. 29
	38	N	March 5
	59	SW	April 13

APPENDIX IV. Temperature Profiles; Section Line Chicago, Illinois-St. Joseph, Michigan, 1963-64.



*No calibration at 30 m, station 4.

25 NOV 1963



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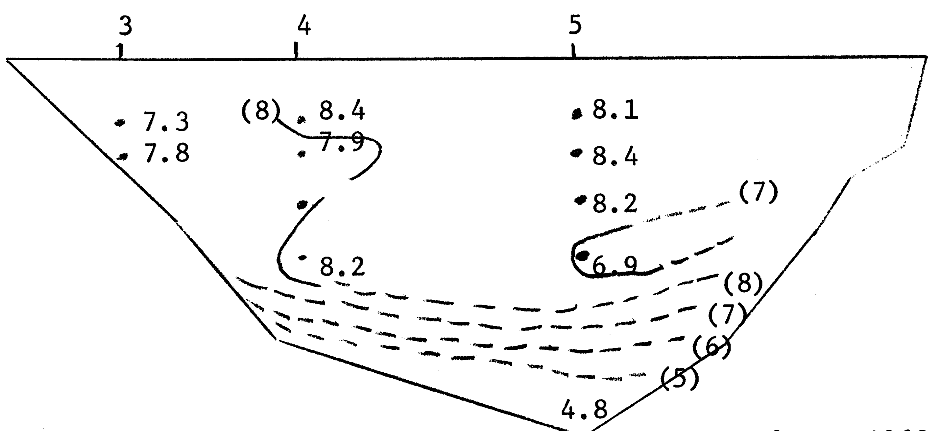

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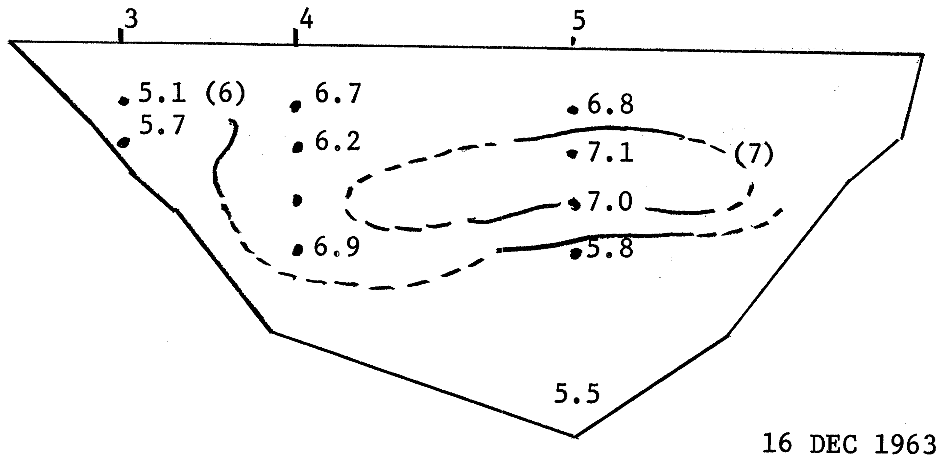

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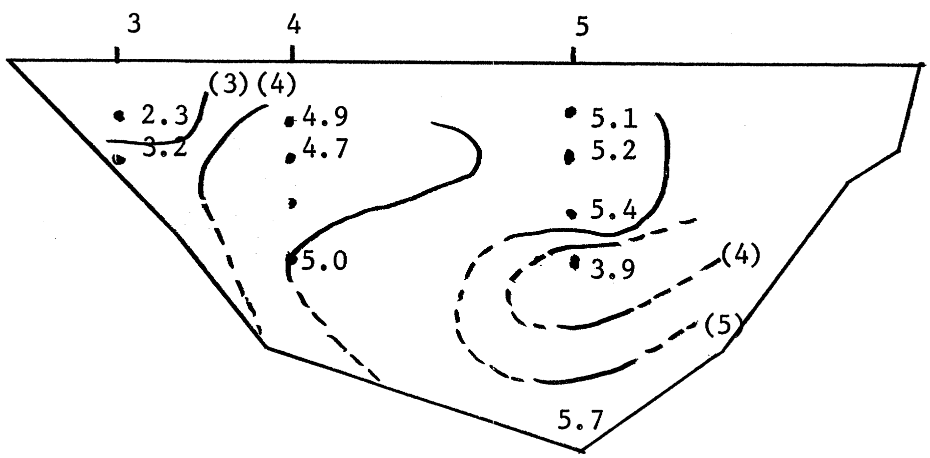

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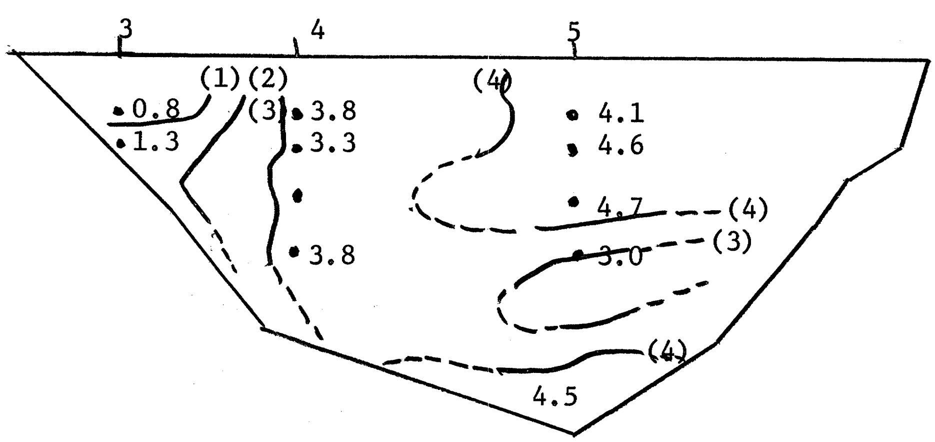

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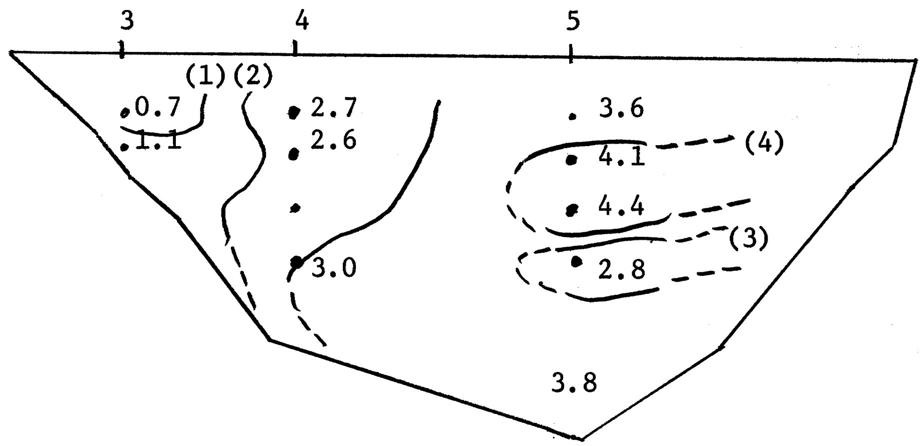
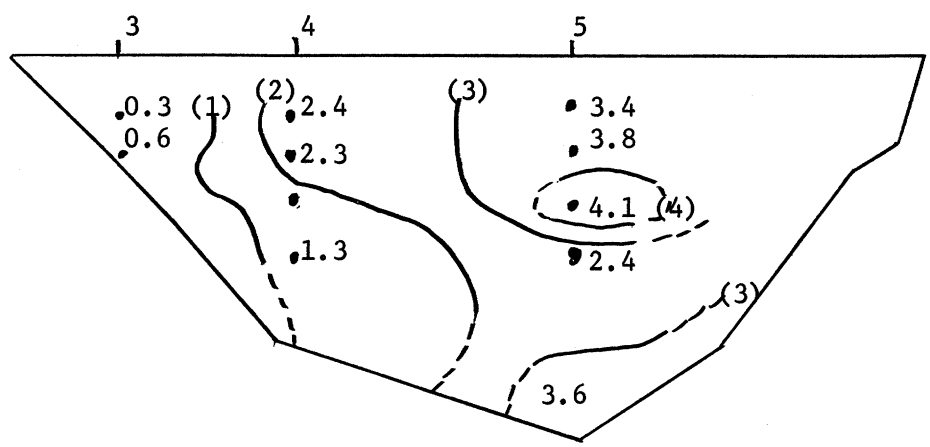
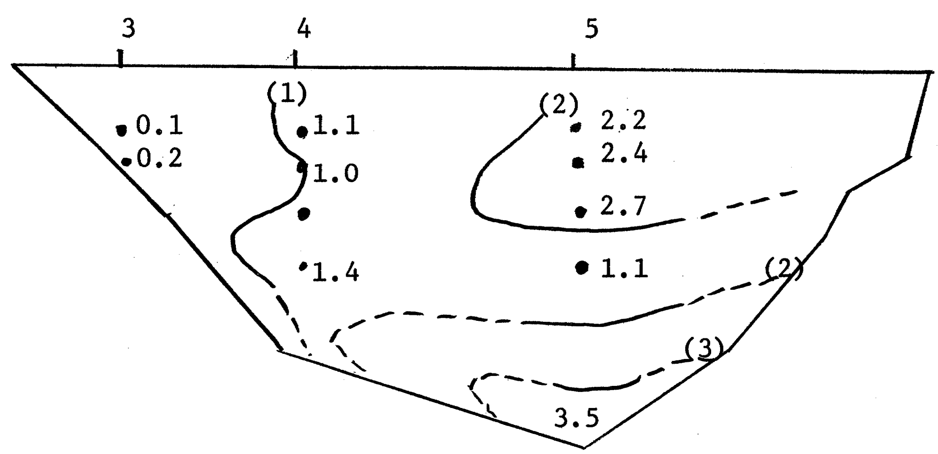


6 JAN 1964



13 JAN 1964



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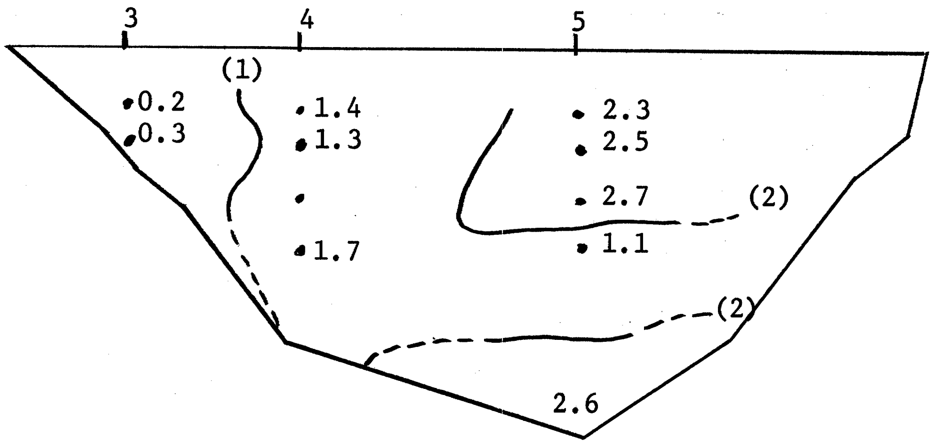

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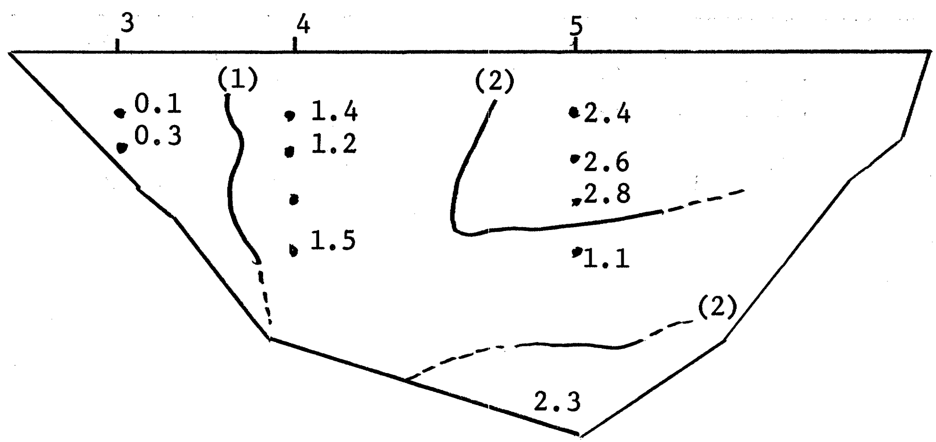

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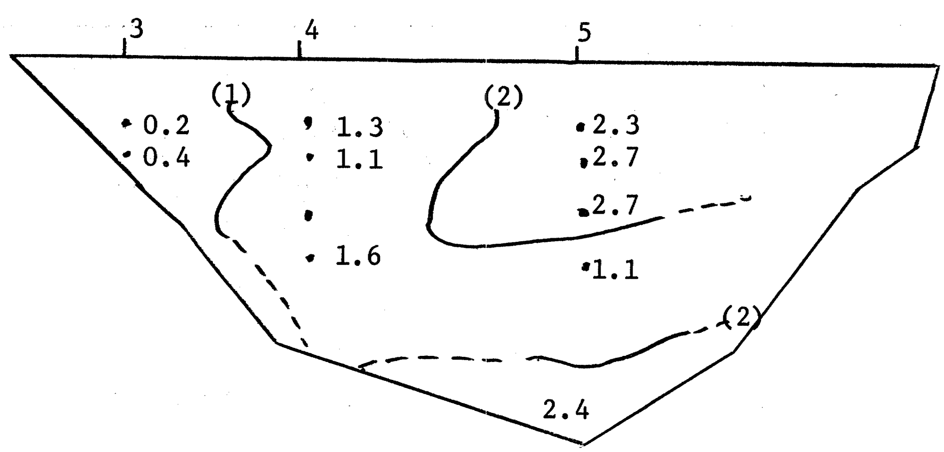

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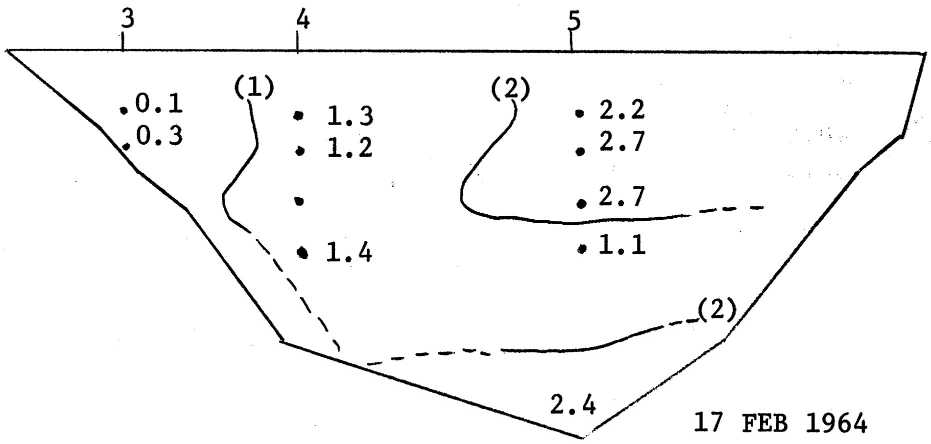

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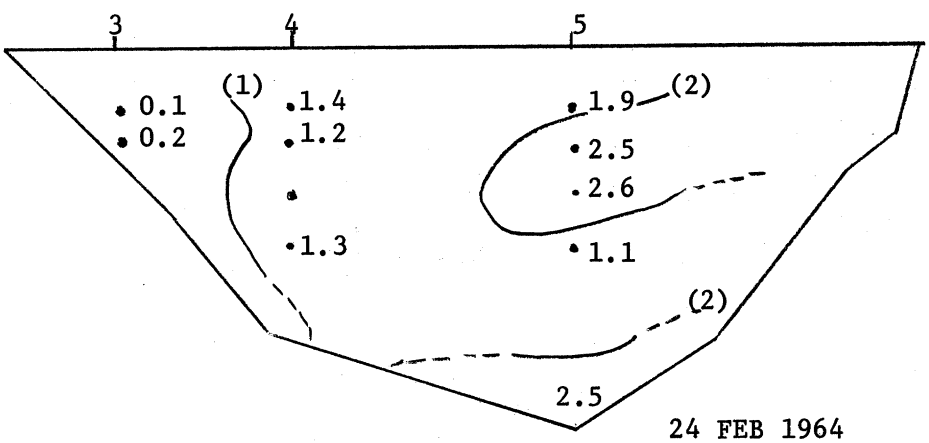

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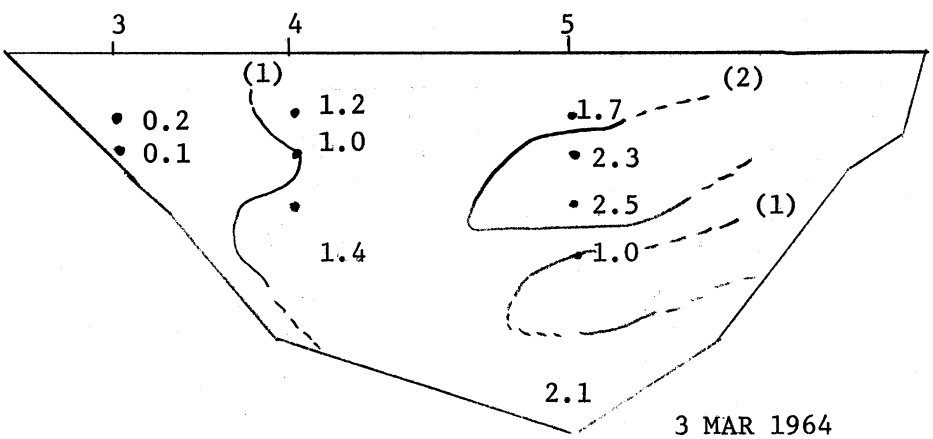

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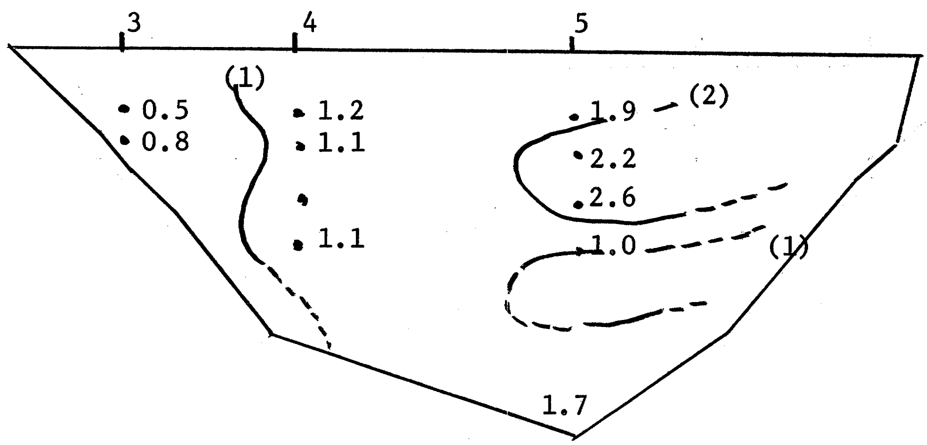

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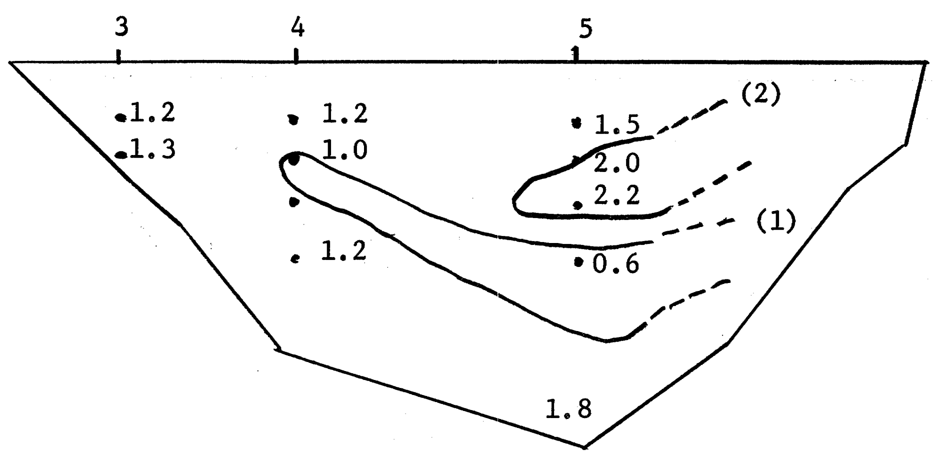

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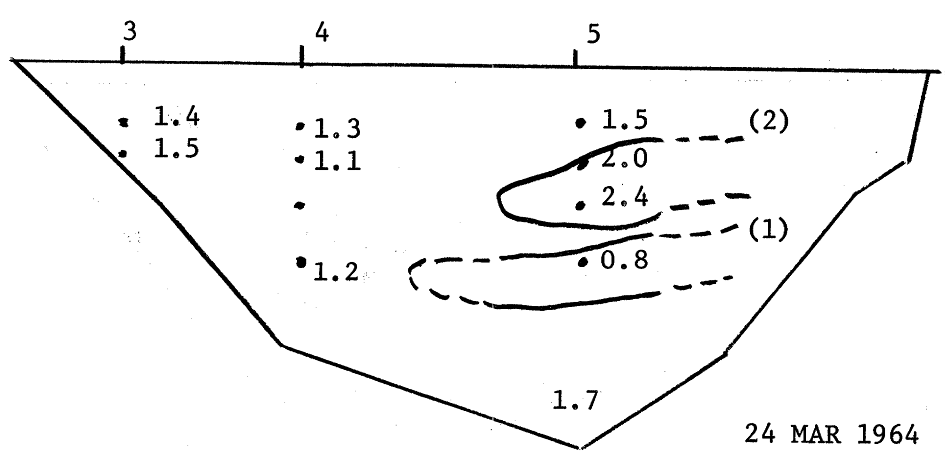

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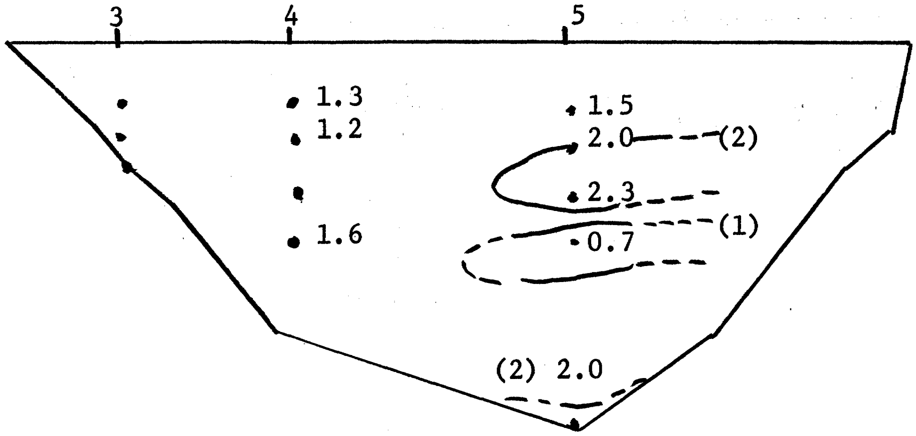

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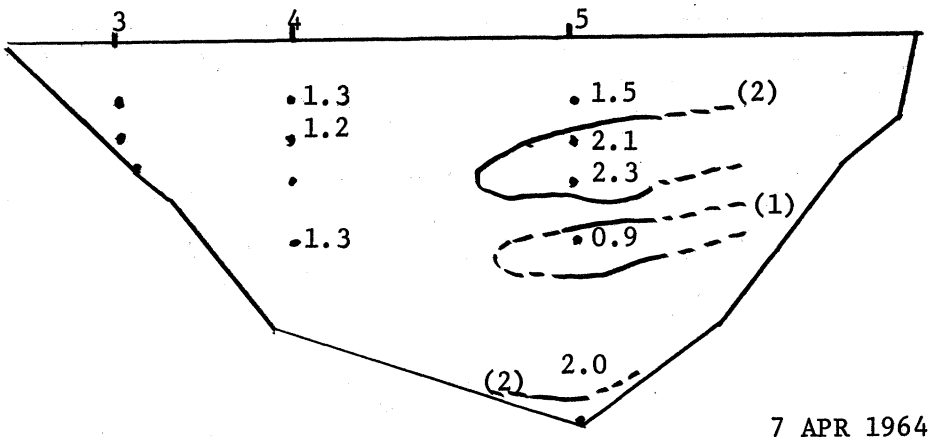
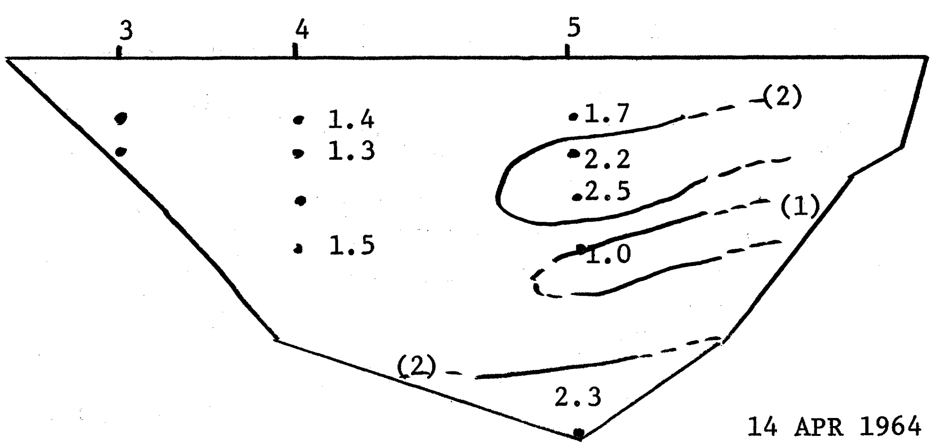


7 APR 1964



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